Appendix B – project description – INTELLISWITCH

Intelligent Quality Assessment of Railway Switches and Crossings

1. Summary

This proposal aims at significantly improving the safety, reliability and operational lifetime of the 3500 switches and crossings (S&Cs) in the Danish railway network. The project is a close cooperation between the Technical University of Denmark (DTU), the Danish rail infrastructure provider Rail Net Denmark and four affiliated European partners with significant expertise within this field. An inter-disciplinary scientific effort is employed to obtain enhanced rail transport reliability and regularity simultaneously with significant savings in S&Cs maintenance costs. The project results will make maintenance based on intelligent fault prediction tools, instead of the presently used regular planned inspections, and it will provide sophisticated tools to prevent hidden faults from developing to failure in the future. In a novel approach, the project will install state-of the-art sensor technology in selected S&Cs and correlate dynamic parameters during train passage with static geometry data from conventional measurement vehicles. Monitoring of the dynamic responses will provide diagnosis of patterns that indicate when components or ballast begin to deviate from fully functional conditions. Modelling of dynamics will identify root causes to signs of degradation. Damage assessment of components identified by anomalous readings will be done by metallurgical examinations. Data and results will be processed by a holistic model that can produce Maintenance Performance Indicators (MPI) for the S&C condition. The correlation of sensor data to measuring vehicle data will allow existing data to be used reliably as input for the MPI model. It is expected that this project will enable optimisation of maintenance procedures, by which appropriate maintenance can be predicted in advance, thus avoiding unscheduled repairs and delays in the railway traffic.

2. Objective of the project

In a railway network of any size switches and crossings (S&Cs) are both a very necessary object as well as a major cost driver for maintenance and renewal. The overall objective of this project is to provide tools for reliable condition assessment of both visible and hidden parts of S&Cs. The specific objectives, within the duration of the project, are:

- To develop a holistic model capable of assessing the condition of individual S&C by combining fault diagnostics input from conventional measurement vehicles and new strategically placed sensors with metallurgical characterisation of key components and dynamic modelling of wheel-rail interaction.
- To use this model to produce one or more maintenance performance indicators (MPIs) for the condition of S&Cs using existing data – such as measuring vehicle data – as inputs, thereby making it possible to replace corrective maintenance with condition based maintenance and renewal.

A successful outcome of the project will have a significant positive influence on maintenance procedures and renewal of railway infrastructure, and the scientific results will be of broad interest in the railway research community and beyond.

3. The main result of the project

The objectives of the project will be achieved by integrating the results of different scientific fields, including fault diagnostics, dynamic modelling, metallurgy and statistical data analysis. Within the duration of the project, the following scientific results are expected:

- Development of a robust condition monitoring system for the diagnosis and prognosis of behavioural changes in system components due to wear & tear or fault occurrences.
- Development of dynamic models to further our understanding of complex interactions between the subsystems in S&Cs under nominal and critical operating conditions.
- Establishment of direct relations between damage evolution and local microstructure in rail and bolt material using advanced metallurgical characterisation techniques.
- Development of an intelligent quality assessment system for the condition for individual S&Cs through models of novel Maintenance Performance Indicators (MPI)

The following societal effects are expected:

- To initiate the transition from correctional to conditional maintenance schemes, where appropriate maintenance can be predicted in advance, thus avoiding unscheduled repairs.
- The scientific insight into degradation mechanisms of both individual components and component interaction during train passage is expected to give recommendations on how to prevent incipient faults from developing into component failure.
- Establishment of a close cooperation between the national railway infrastructure provider and Danish academia to initiate research and education within a field of sustainable transport that focuses on railway infrastructure issues.

4. Background and hypothesis / research question of the project

Background: Today 25% of the global CO_2 emissions come from transportation. According to the latest white paper on transport from the European Union[1], railways are the key to obtaining a sustainable multi-modal interoperable transport network. In order to retain the competitiveness of modern railway transportation a high reliability, efficiency and safety of railway systems is crucial.

Switches and crossings (S&Cs) are an essential part of any railway network as they enable trains to be directed from one track onto another at railway junctions, allowing for necessary flexibility during train operations. At the same time they are also the most vulnerable part of the railway network, suffering from peak stresses because of their greater geometric complexity compared to normal tracks and moving parts. As a critical part of the railway poorly maintained S&Cs have a detrimental impact on railway operations.

3000 trains run every day on the 2000 km of the Danish railway network, annually transporting 170 million passengers and 15 million tons of freight. In this network there are 3500 S&Cs which are currently inspected manually on a regular schedule by staff who determine the condition of each S&C, supplemented by automated inspections with measuring vehicles. In some S&Cs, critical components are worn down quickly and need to be repaired or replaced every few years. Out of the 40M€ condition-based maintenance budget, S&Cs represent around 50% of the expenses, and unscheduled repair of S&Cs are responsible for a significant portion of temporary speed reductions and associated delays. As recently as August 2014 a train was derailed at Copenhagen Central Station because of a S&C component failure, affecting several thousands of passengers for 3 days. The latest major incident on the Danish railway network was the derailment of a freight train in Southern Jutland during the winter of 2012, where 6000 metres of tracks were damaged and almost all traffic to Germany was closed for weeks. This was, at least in part, caused by failure of a S&C component. Most of the S&Cs in Denmark were installed more than 30 years ago and therefore more than 1500 S&Cs are expected to be scheduled for renewal during the next several years. This means huge investments in S&Cs in the near future, where an effective selection of new types of S&Cs with optimal maintenance schemes would have a significant future impact.

State of the art: Variations in the rail profile at S&C cause severe local load conditions, such as sudden changes in track curvature at the switch blade and discontinuities in the running surface and stiffness near the crossing nose. Calculations show that contact forces are many times higher at critical junctions compared to static wheel loads[2]. S&C components suffer from complicated damage mechanisms including wear, plastic deformation and rolling contact fatigue[3]. The increased load conditions are transferred into the bolts and screws joining S&Cs, where the flexing and displacement of the rails can cause cyclic tensile and shear loads which provoke fatigue failure in both bolts and rail joints[4]. Although the failure mechanisms in S&C are directly linked to the dynamic forces (due to passing trains) on the railway tracks, they are neither well characterised nor understood in spite of their importance in the railway infrastructure[3]. The dynamic forces are transient by nature and of relatively large magnitude. They can be modelled on macro and micro scales using Multibody Dynamics[5-6] and Finite Element Methods[7-8]. Holistic computer models can simultaneously account for: i) soil dynamics and uncertainties related to stiffness and damping model parameters[9-13]; ii) structural dynamics[14] between the ballast-sleeper-pad-rail components; iii) dynamic loading between wheels and rails leading to contact[7], impact[8], elastic deformation[7,15], plastic deformation and finally wear and damage[16]. Such holistic models can be validated using experimental data (strain and acceleration) with full-scale field testing procedures[15] under certain well-defined

and controlled operating conditions. Condition monitoring of S&Cs focuses very much on point machines (actuator responsible for switching) due to the crucial role they have. Different techniques are applied ranging from direct thresholds of signals readily available such as voltages or currents[17-18] to model-based diagnostics[19-21]. Adaptive neuro-fuzzy systems[22-24] have been able to achieve both diagnosis and prognosis with good performance, although they rely on measured signals that may not be readily available. Sensors capable of measuring strain and acceleration are currently highly reliable. Measuring strain in metal, wood or concrete has also become very reliable with the appearance of glass or very recently also polymer optical fibre sensors. Thus recent progress in signal-based monitoring theory and sensor technology can directly be implemented in the project. Classical techniques in system monitoring and prediction in industrial processes are traditionally aimed at low data rates and few variables[25-26]. Mounting sensors on industrial installations such as S&Cs inevitably results in high frequency, multivariate streams of data, which are large and complex with non-traditional properties such as very high cross- and autocorrelation characteristcs[27-28]. Collection, manipulation, and final analysis of these data are uncharted territories in current literature and present great challenges both practically and research-wise.

Hypothesis: By using an interdisciplinary approach, a reliable intelligent quality assessment with one or more Maintenance Performance Indicators (MPIs) for individual S&Cs can be integrated with existing fault prediction tools (such as measuring vehicles), and can be used to predict necessary repairs in advance thereby replacing regular manual inspections.

5. Innovative value, impact and relevance of the project

Maintenance and renewal of S&C is today almost completely based on subjective assessment of their conditions. In recent years there have been invested huge amounts of resources in the Danish railway network (annual budget of 0.8 billion €) with major renewals and expansions planned. An objective assessment of the condition of the new assets will enable a larger degree of condition based maintenance, which is internationally recognized to result in decreased life cycle costs[29]. To make this possible, the primary scope of this project is to develop a new model, specified by one or more MPI's, creating a basis for incorporating existing data in new intelligent decision support modules in regards to condition based maintenance.

Scientific results of the project will include not only advances in theories and methods of the individual disciplines involved, but also integration of the knowledge between different fields to create the MPI´s determined from intelligent data analysis tools to thereby make use of the entire envelope of information available. Such a holistic approach has not been attempted before due to the ambitious scope and multidisciplinary knowledgebase requirements. In that regard the project team has the perfect balance of diverse technical expertise for the theoretical developments with immediate practical implementation possibilities. This project is expected to generate interest from various international stakeholders, such as infrastructure managers, contractors and research institutions.

As a whole, this project is anticipated to create a basis for more intelligent, data driven decision support in regards to maintenance and renewal, which will optimize life cycle costs and ultimately increase future reliability, punctuality and safety of the railway infrastructure. Improving passenger comfort and travel experience will make rail travelling more attractive and be a major step towards ensuring a more sustainable transport sector.

6. Projects methodology and results

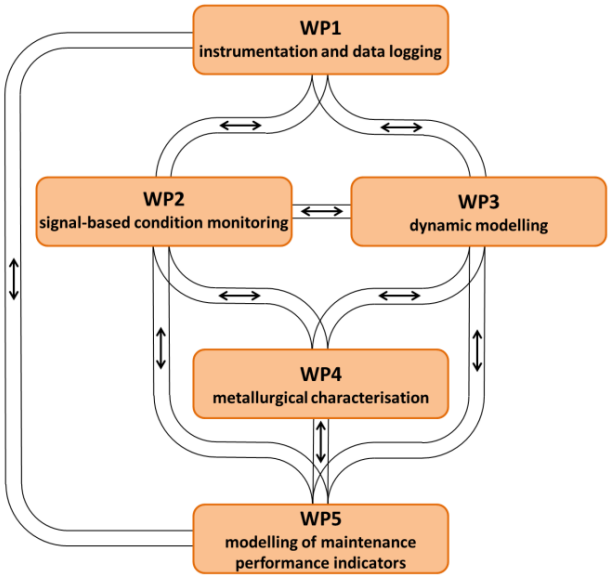


Figure 1: *Flowchart illustration of how the five work packages will work together to create a MPI model. The overall project is based on a multidisciplinary approach, and only through a close cooperation between the work packages can the goal of the project be achieved. New data (WP1) will be processed (WP2), modelled (WP3) and examined (WP4) before a final product can be achieved (WP5). The entire endeavour is designed to be an iterative process based on exchange of information between all of the work packages.*

The project is divided into 5 mutually supportive work packages (WPs) which will work in close cooperation and provide feedback to each other as illustrated in figure 1. The purpose of *instrumentation and data logging* WP is to supply the other WPs with measurement data. The relevant motions of individual parts of the selected S&Cs will be monitored by state-of-the-art sensor technology. Real-time response data will be delivered to the other work packages based on their specific needs. The *signal-based condition monitoring* WP will investigate sensor measurements during train passage to identify deviating patterns dependent on the condition of many parameters, wear, tear, and incipient or abrupt faults in S&Cs. These responses will be used to highlight salient features addressing the dynamical evolution of the system towards worn conditions that might ultimately cause a failure if not repaired in time. The *dynamic modelling* WP will develop simulation models based on the state-of-art computational tools for predicting how faults will change the dynamic responses during train passage. Holistic models will be carefully validated using input data from other WPs, and in return showing where and what type of sensors should be mounted to provide appropriate responses for condition monitoring. Based upon input data from the other WPs, the *metallurgical characterisation* WP will extract specific S&C components from the rail network, examine them and identify damage mechanisms. Feedback will provide validation to the other WPs for locating potentially damaged or worn sections before failure takes place. Finally, data and results from the other WPs will be processed by the *modelling of maintenance performance indicators* WP, which will develop a model that can produce one or more MPI for the S&C condition. The objective is that data from measuring vehicles can be used reliably as input for the MPI model to avoid need for further implementation of expensive sensors in the future.

WP1 instrumentation and data logging:

State-of-art sensors, such as fibre optic accelerometers and strain gauges, will be installed and used to monitor relevant motions of certain components in selected S&Cs, providing precise dynamic data which are not available at present from measurement vehicles. The project will focus on applying the S&C-based sensors in a selected number S&Cs of type 1:14 with radius 500, which represents the future-oriented S&C design approach in Denmark and provides an ideal basis for developing and proving the MPI model. Specification of the sensors needed and collection/interpretation of data will be carried out by DTU, while Rail Net Denmark will supervise, plan and carry out the physical installation in the infrastructure. The dynamic responses from the sensors during operations will be logged, processed and verified, including

conducting sanity check and time synchronization with measurement vehicle data. If necessary, changes in sensor equipment/placement will be carried out, based on feedback from the other work packages. The following results are expected:

- Installation of sensors in selected S&Cs identified by Rail Net Denmark
- Data collection and validation to provide input for the other work packages

WP2 signal-based condition monitoring:

Monitoring of S&Cs is addressed by focusing on the main components that severely affect the system reliability. The combination of robust diagnostic and prognostic techniques will be an asset to achieve effective predictive maintenance, as shown in other engineering areas[30-33]. Identification and statistical characterization of the nonlinear phenomena driving the wearing of components will be a primary goal. Methods from signal-based fault diagnosis and change detection will be employed and further developed to meet the high complexity of S&Cs. Estimation methods will be developed to monitor parameters that can be used to make prognosis of wear or faults under development. The research will focus on finding methods that are robust to normal variations due to changing weather conditions or track usage, yet sensitive to changes that indicate component wear. The following results are expected:

- Characterization of the region of fully functional behaviour of S&Cs
- Identification of S&Cs health indicators to be used for the monitoring of the system
- Development of a robust condition monitoring system for diagnosis and prognosis of abrupt and incipient deviations from the fully functional behaviour of S&Cs components.

WP3 dynamic modelling

Simulation models based on the state-of-the-art computational tools will be developed for showing how incipient and abrupt faults will change the dynamic responses. Holistic models on the macro and micro scales will give insights into stress, deformation (strain) and accelerations experienced by the various parts of S&Cs during train passage with a high level of fidelity. After experimental validation such computer models will be used to advance our understanding of the complex interaction among all subsystems under nominal and critical operation conditions. The calculated responses will be functions of the overall condition of the S&C, and of its individual components and geometrical properties, as well as train mass and passage velocity. When components become worn out and plastically deformed, the calculations will in principle show how incipient and abrupt faults will change the dynamic responses during train passage. The modelling is expected yield the following results:

- Development of a holistic mathematical model that can describe soil-ballast-sleeper-pad-rail-wheel dynamic interactions.
- Identify parameters which are signs of degradation.
- Provide guidelines on how to best avoid faults from developing.

WP4 metallurgical characterisation

S&C components identified by anomalous readings will be extracted for extensive metallographic examinations, including electron microscopy, x-ray diffraction residual stress measurements and nano-hardness profiles. Special attention will be given to correlations between strain measurements and component condition. 3D X-ray tomography[34] will be used for three-dimensional mapping of fatigue crack networks on rail surfaces and in bolts/screws. Laboratory investigation[35] using controlled conditions to support the identification of failure mechanisms by establishing relations between cracks and microstructure. In-situ fatigue facilities for Scanning Electron Microscopy will be used to follow crack formation and propagation on a microscopic level. The following results are expected:

- Damage assessment of components identified by anomalous readings, providing feedback to locate potentially damaged or worn out sections before failure takes place.

- Identification of failure mechanisms in rails and bolts/screws using metallographic examinations of components from service condition and controlled laboratory tests.
- Deliver recommendations for improvements in material choice and maintenance.

WP5 modelling of maintenance performance indicators

All data generated from the project will be processed and developed into a model that can produce Maintenance Performance Indicators (MPIs) for condition of the S&Cs. Issues that have to be addressed include the abundance of fast streaming and complex data sets generated from conventional measurement vehicles and the state-of-the-art sensors implemented in selected S&Cs, as well as the misalignment of data streams as this often necessitates the development of dynamic time warping techniques before analysis[36-37]. One of the main challenges for data that arrive from a variety of sources at high volume is to lower the dimensionality by taking advantage of the correlation structure among the variables to enable extracting important features. New methods will be needed to address the issues such as: Statistical Process Control and multivariate feature extraction and variable reduction[38]. Methods in line with Multi-way Principal Component Analysis[39-40] and Sparse Principal Component Analysis[41-42] inevitably will have to be explored with "Big Data" issues in mind. The expected main results are as follows:

- Preparation of data from existing measurement vehicles.
- Development of a model which summarises inputs from other work packages and is able to deliver one or more MPI´s for the condition of individual S&Cs.
- Correlation of sensor data to measuring vehicle data, so that vehicle data can be used reliably as input for the MPI model without requiring implementation of expensive sensors.

Uncertainties and risks

A multidisciplinary approach is necessary to achieve the goals of this project and success depends on close cooperation between the different work packages. Cooperation problems between the work packages or between scientific and industrial partners could pose a risk, as many of the partners have not worked together before. The PI will strive to keep the project on track and focus on keeping the different work packages well coordinated with each other, including the necessary flow of information and feedback needed for a favourable outcome of the project.

The damage mechanisms of S&Cs are complicated, and with different S&Cs being exposed to different loading conditions there is a risk that neither dynamic modelling nor metallurgical characterisation can establish the necessary relations. Therefore the project will be restricted to 1:14 with radius 500 type S&Cs that are exposed to relatively well-defined loading conditions, such as commuter traffic with a specific train type (f. ex. S-train).

Damage mechanism may turn out to be too complicated for a single MPI to give reliable results. A series of MPIs may be necessary to deliver a satisfactory outcome. The success criteria would be to achieve an improvement over the current subjective manual inspections.

It is a risk that the current measurement vehicles used in Denmark today, from the company Eurailscout, do not have the necessary input or sensitivity required for detecting incipient or developing faults. Delft University of Technology in the Netherlands (with which collaboration already exists) has had projects going on for some years with dynamic acceleration sensors mounted on the axles of trains for detecting small defects in the rails and switches. As it happens, Eurailscout is directly involved in those projects, and if necessary their experiences with these measurements systems could be used to upgrade the vehicles operating in Denmark.

7. Project plan

The project is divided into 5 WPs. Each WP has a WP leader from DTU and a WP 'benefit owner' from Rail Net Denmark in order to ensure an optimal synergy between research and application. The scientific WP leaders are all highly experienced in research within their respective fields as well as in leading projects. The WP benefit owners, who are Rail Net Denmark engineers, are each highly specialized in their respective technical fields including metallurgy, welding, geometry, measurement techniques, asset management, data analysis and life cycle management. The WP leaders are responsible for the scientific and technical work and the WP benefit owners will contribute to the definition of the specific detailed goals and to future directions for the investigations within the WP. The WP benefit owners will also give necessary available technical input and contribute to the evaluation of the results within their respective WPs.

WP1 instrumentation and data logging
Novelty: State-of-the-art sensor technology (as semiconductor, MEMS, and fibre optics) will be installed on selected S&Cs to acquire dynamical data about mechanical stress and accelerations in connection with the rail network utilization.
Scientific coordinator: Associate Professor Roberto Galeazzi, DTU Electrical Engineering
Industrial coordinator: Project Manager Tom E. Thøgersen, Rail Net Denmark
Junior personnel: 1 PD (2 months)

WP2 signal-based condition monitoring
Novelty: Development of a robust signal based condition monitoring system for the diagnosis and prognosis of abrupt and incipient wearing conditions which may ultimately cause failures in one or more components if not maintained in time. The robustness of the condition monitoring system will be guaranteed by a multi-domain multi-indicator approach, which is a clear novelty in the area of predictive maintenance for railway networks.
Scientific coordinator: Associate Professor Roberto Galeazzi, DTU Electrical Engineering
Industrial coordinator: Senior Track Specialist Martin H. Sørensen, Rail Net Denmark
Junior personnel: 1 PhD (3 years); 1 PD (1.5 year)

WP3 dynamic modelling
Novelty: Mathematical models anchored on experimental validation and linking several subdomains (soil, ballast, sleeper, pad, rail and wheel) will be a fundamental step forward in the development of novel simulation tools to describe the phenomena of overloading and wearing of system components.
Scientific coordinator: Professor Ilmar F. Santos, DTU Mechanical Engineering
Industrial coordinator: Track Specialist Rene X.V. Fongemie, Rail Net Denmark
Junior personnel: 1 PD (30.5 months)

WP4 metallurgical characterisation
Novelty: State-of-the-art X-ray tomography equipment well suited for studying rails and bolts is currently being installed at DTU Wind and in situ SEM fatigue facilities will be acquired. Complemented by advanced electron microscopy, these techniques will open up a new scientific area for quantifying damage mechanisms and its relation to the microstructure.
Scientific coordinator: Senior Researcher Hilmar K. Danielsen, DTU Wind Energy
Industrial coordinator: Technical System Responsible Carsten J. Rasmussen, Rail Net Denmark
Junior personnel: 1 PhD (3 years)

WP5 modelling of maintenance performance indicators

Novelty: State-of-the-art sensors and measuring vehicles produce complex high-dimensional spatio-temporal data which require development of novel statistical modelling and monitoring techniques.

Scientific coordinator: Professor Bjarne K. Ersbøll, DTU Compute

Industrial coordinator: Team Leader Jacob B. Nicolaisen, Rail Net Denmark

Junior personnel: 1 PD (31 months)

The project will include 5 post docs (PDs) and PhD students, each allocated to a WP. To ensure a good and broad education of the PhDs and PDs each will be associated to a second WP which is closely related to their own. Affiliated international partners will serve as hosts during a foreign stay, while PhDs and PDs from affiliated partners are also expected to visit Denmark. An overview of the project timescale is illustrated as a Gantt chart on the following page. Biannual meetings will be held for the whole team to ensure the direct flow of information between WPs. Short quarterly reports on the activities within each WP will be written and circulated to all participants. The steering committee and the advisory board will each meet annually. When necessary, additional ad-hoc meetings will be held. A workshop with invited international railway experts is planned for 2016 Q4. Milestones given for each work package are listed in the table below:

Milestone	Deadline
WP1	
Initial sensing technology specifications	2015 Q2
First S&C equipped with sensing and data logging equipment	2015 Q3
Start of data delivery	2015 Q4
WP2	
Identification of features addressing deviant behaviour of S&C components	2016 Q3
Indicators developed for assessing the level of S&C functionality	2017 Q2
Evaluation of the monitoring performance of the proposed indicators	2018 Q1
WP3	
Finish macro model	2016 Q1
Finish detailed model of S&C	2017 Q3
Identify dynamic responses from incipient faults	2018 Q3
WP4	
Report on damage characterisation in bolts and screws	2017 Q1
Report on damage characterisation in rail components	2018 Q1
Evaluation of damage mechanisms and suggestions for improvements	2018 Q3
WP5	
Exploratory analysis of the measurement data completed	2016 Q3
Empirical validation of the MPI-model completed	2018 Q3
Business model finalised	2019 Q1

The project is set to deliver a MPI model to Rail Net Denmark within 4 years. The strict time schedule stems from a sense of urgency because of the need to replace a large amount of S&Cs due to lifetime assessments adjustments which have reduced expected life cycles. The project will compensate for the relatively short project span by selecting heavily loaded S&Cs for sensor installation, where critical components need to be repaired or replaced every few years, as it is easier to measure a larger magnitude of degradation and it helps minimizing small stochastic variations in the processes that affect the degradation of the S&Cs.

Time schedule	2015			2016				2017				2018				2019
	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1
WP1																
Sensing technology specifications																
Procurement and installation																
Automated validation and calibration																
Production logging																
WP2																
S&C normal behaviour identification																
Signals features extraction																
Condition indicators																
Condition estimation algorithms																
WP3																
Macro model																
Detailed model of S&C																
Wheel-rail dynamics																
Validation and model refinement																
WP4																
Specimen selection																
Damage assessment																
Laboratory testing																
Identification of damage mechanisms																
WP5																
Exploratory data analysis																
Build combined MPI model																
Feasibility check																
Extrapolation to other S&C																
Business model																

8. Projects international dimension

In INTELLISWITCH, the international dimension will be covered at two levels: i) collaboration essential to the project; ii) other international collaboration important for the project.

At level i) four affiliated international partners are directly involved in the project: Chalmers University, Sweden, for metallurgical expertise; NTNU, Norway, for dynamic modelling; University of Birmingham, UK, for fault diagnostics and TU Graz, Austria, for rail quality behaviour prognosis. They have been chosen because of their internationally leading scientific contributions in their respective topics, supplementing the Danish partners with their expertise. All four affiliated partners have expressed strong interest in INTELLISWITCH, mainly because of its interdisciplinary scientific approach and the significant involvement of Rail Net Denmark staff. This cooperation will facilitate a vital knowledge transfer to the project. It is expected that this tight network between Danish and leading European researchers will form the foundation for future cooperation and Danish participation in larger (f. ex. EU funded) projects in the field of sustainable railway transport.

At level ii) nobody is yet included, but a group of 8-10 experts will be chosen among the strong international networks the scientific partners have within their respective fields and among the following experts from the railway industry (primarily infrastructure managers): Peter Søderholm, Trafikverket, Sweden; Frode Teigen, Norwegian National Rail Administration, Norway; Markku Nummelim, Finnish Transport Agency, Finland. This group will be consulted for advice as required and will be informed about new results by receiving our publications. They will all be invited to take part in the international workshop , and if relevant they may be invited for shorter stays at a Danish partner.

9. Legal and ethical aspects

Data of commercial importance for Rail Net Denmark will be protected according to confidentiality clauses in the collaboration agreement (to be made). No ethical issues are connected with this research.

10. Publication and promotional strategy and exploitation of results

Concerning scientific papers, the dissemination strategy aims at publishing the results in the most appropriate international journals and at presenting the results at key international conferences. In publishing papers, the DTU publication strategy (to be launched shortly) will be followed, thereby also assuring correct ethical behaviour. To avoid conflicts of interest, all manuscripts will be distributed to all partners 3 weeks prior to submission and any mandatory comments will have to be dealt with before submission. In the unlikely event that the partners cannot agree on a solution, the Steering Committee (see Section 11) will have the final decision. It is expected that the 4 scientific WPs (WP2-5) each will publish at least 2 papers per year and slightly more towards the end of the project. Also we will assure that each PhD and PD publishes at least 3 papers. A further goal of our dissemination strategy for the scientific papers is that 50% or more should be with joint authorship from more than one partner.

Participation in the relevant conferences is considered essential to promote the results of INTELLISWITCH and to expand the international network. Selected themes mostly related to WP4 will be included in the planning and organization of one of the international symposia on Materials Science held annually at the DTU Risø Campus (f. ex. for 2018). The applicant is behind the organization of this series of symposia, which in 2014 is held for the 35th year. Each symposium has attracted forefront materials scientists and the proceedings are treated by the international community as a major resource. An international workshop on modelling with Big Data will be held at DTU Compute. Trade conferences relevant for presenting results of this project include: The Danish Railway Conference, the IAF Congress, Railway Engineering, the Nordic Rail, International Convention of the Working Committee on Railway Technology (ÖVG), and the World Congress on Railway Research.

Concerning dissemination to the broad international railway community our strategy is primarily to make use of leading railway trade magazines such as: International Railway Journal, Railway Gazette, Eisenbahntechnische Rundschau (ETR), Der Eisenbahningenieur and European Railway Review. On the Nordic level we plan to make use of trade magazines such as: Nordisk Infrastrukur and Nordisk Järnbane Tidskrift (NJT). On the national (Denmark) level we plan to publish in Danish Rail Sector Association magazine “Signal”, and Rail Net Denmark’s company newspaper “Baneavisen”. But the results will also be communicated in other fora like the Danish Metallurgical Society and Danish Automation Society.

All direct contact with the press shall be handled together with Rail Net Denmark.

Rail Net Denmark is very keen on using all relevant results directly and the transfer of knowledge is assured because each WP has a leader from DTU and a benefit owner from Rail Net Denmark.

If relevant, patents will be applied for and intellectual property rights will be divided according to the general practice used for research projects funded by the research councils.

11. The participating parties, project management

Project partners

The established project consortium consists of project partners from academia and industry who have the necessary competences to successfully achieve the aims of the project, both in the scientific and practical fields. Collaboration between the individual academic partners and Rail Net Denmark is already well established, whereas the collaboration between the academic partners on rail topics is new. The bigger goal of the present proposal can however, only be reached by combining forces and everybody is highly motivated to get the new collaboration started and to benefit from the broader interconnected network.

Below follows a list of partners:

DTU Wind Energy, Material Science and Advanced Characterisation: The research activities of this section deal with the characterisation and modelling of metallic materials, the objective being to perform metallurgical science on a high international level with particular focus on materials and components for wind energy purposes. Such areas include rolling contact fatigue of wind turbine bearings, which is closely related to the rolling contact fatigue seen in train wheel/rail interactions. The section has specialised laboratories for materials science, including a broad range of electron microscopes, x-ray equipment and fatigue testing facilities.

DTU Electrical Engineering, Automation and Control Group: The research activities of the group focus on fault diagnosis, and fault tolerant control as well as mobile and modular robotics. The group is internationally leading in the area of fault diagnosis and prognosis where novel signal based and model based techniques have been successfully integrated for the creation and development of robust condition monitoring systems. Industrially relevant results have been achieved in several engineering domains, with consequent patenting and licensing of diagnostic tools to national and international companies.

DTU Mechanical Engineering, Section of Solid Mechanics: Main research topics at this section are mechanics of materials, strength and dynamics of structural components and multiphysics systems, machine elements and mechatronics as well as structural and multidisciplinary optimization, which is closely related to the rolling contact fatigue seen in train wheel/rail interactions. The section has specialised workshops and laboratories for dynamic and vibration studies, including a broad range of testing facilities.

DTU Compute, Statistics and Data Analysis: The research of the section is focused on methodological development and application of statistics and data analysis relevant for solving problems in engineering sciences. Research topics include: industrial design of experiments, statistical process control, computational data analysis and analysis of “Big Data”. The section has a strong collaboration with the railway industry, including projects on the IC4 train breaking system with DSB, and different aspects of track deterioration with Rail Net Denmark.

Rail Net Denmark: Rail Net Denmark is a public company under the Danish Ministry of Transport which has the responsibility for maintaining, renewing, and developing the railway network. The mission is to ensure that Denmark always has the capacity and reliability to operate trains, so that passengers have an attractive means of rail transport, today and in the future. In this way, it forms the foundation for one of the safest and most environmentally friendly methods of transporting people and freight on land. Rail Net Denmark is currently in the process of developing the railway to cope with future requirements, so that in the future it is possible to double the passenger and freight transport on the railway network.

Below follows a list of international affiliated partners:

TU Chalmers, Dept. Materials and Manufacturing Technology, CHARMEC: Chalmers Railway Mechanics (CHARMEC) was established in 1995 as a Centre of Excellence in cooperation with the Swedish Transport Administration and various industrial partners. The overall goal of the Centre is to achieve increased quality in railway transportation in addition to lowering the production, maintenance, operational and environmental costs. The interaction of various railway mechanical components is given special consideration. During this project CHARMEC will mainly contribute to the metallurgical investigations.

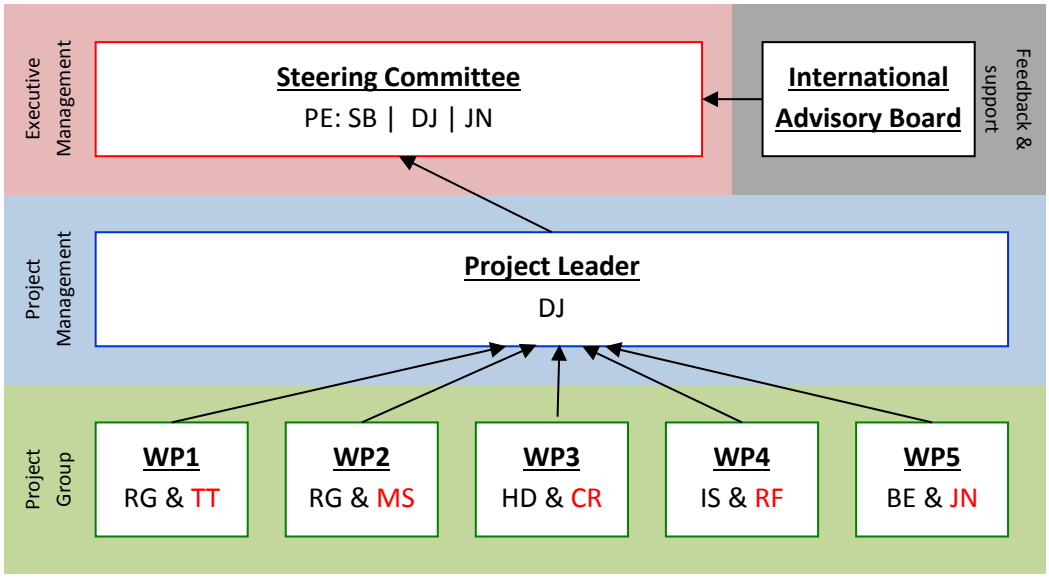
NTNU, Dept. Civil and Transport Engineering: This is one of the largest departments at NTNU, and transport infrastructure research is one of the focus areas dealing with all aspects of road technology and railway track technology, with laboratory facilities for pavement material testing and large scale track durability testing. The railway group has expertise in numerical modelling and experimental studies of track infrastructure, including development of simulation models for S&Cs, condition monitoring of railway tracks, ballast materials testing and characterisation. During this project NTNU will mainly contribute to the dynamic modelling activities.

University of Birmingham, Centre for Railway Research and Education: The Centre provides fundamental scientific research, knowledge transfer and education to the international railway community. The Centre brings together expertise from across the University of Birmingham to meet the challenges of the future, delivers world class research within railways and offers an expanding portfolio of high quality education programmes. During this project University of Birmingham will mainly assist with expertise on fault and failure scenarios for railway networks, and on design of condition monitoring systems for S&Cs.

TU Graz, Dept. Railway Engineering and Transport Economy: The department has worked for more than 15 years with track quality behaviour prognosis and life cycle costs (LCCs) analysis of railway assets, especially for track superstructures such as S&Cs. The department is working internationally for different railway infrastructure companies as SBB and JBV, evaluating LCC of existing railway assets, forming a database for setting up LCC based strategies and defining new LCC based track strategies in evaluating the LCC of different options. During this project TU Graz will mainly assist with LCC considerations.

Project management

The aim is that this project shall be as much an innovation project as a scientific project. The project is furthermore highly interdisciplinary, and overall success relies on successfully interlinking the 5 WPs. Therefore, we have chosen the project management model used by Danish governmental institutions (including Rail Net Denmark) which is based on PRINCE2®. This model has three levels of participants, as illustrated in the figure below.



The project group consists of the scientific and technical staffs that carry out the bulk of the work. The WP leaders (names given by initials in black in the figure above) are responsible for the scientific and technical work within their respective WPs. Each WP also have a WP benefit owner (names given by initials in red in the figure above) ensuring close coordination between the technical challenges/wishes from Rail Net Denmark and the new scientific and technical results obtained in the project. The project leader (the PI) is responsible for coordination of technical and administrative activities and is also responsible for quarterly reporting to the steering committee. The steering committee, which has an executive management role, including definition of success criteria and decision authority on change requests, is headed by a project executive from Rail Net Denmark (Technical Director Søren Boysen from Rail Net Denmark), who is in charge of the business case. The steering committee will have regular meetings to be able to take decisions about change requests and other executive work. The day-to-day executive management will be between the Senior User (Team Leader Jacob Bech Nicolaisen from Rail Net Denmark) who ensures the interests of the end users, and the Project Leader (Professor Dorte Juul Jensen from DTU) who ensures the interests of the suppliers. Dorte Juul Jensen will be supported by an authorized administrator from DTU Wind Energy dealing with all financial issues, at no cost for the project.

An international advisory board with 3 experts from the railway industry (primarily infrastructure managers), but very well informed about the scientific developments, will be appointed and meet with the steering committee once per year. We plan to choose the 3 members from among the following: Arne Nissen, Trafikverket, Sweden; Wassim Badran, Swiss Fedreral Railways, Switzerland; Albert Joerg, Voestalpine Schienen GmbH, Austria; Morten Tanggård, Jernbaneverket, Norway; (none of them will be approached before funding

has been granted). The international advisory board will provide feedback and opinions on the progress of and the plans for INTELLISWITCH, but has no executive power. The board members will also be invited to participate in the international workshop (see section 8).

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