STAGE 10

TRIENNIAL REPORT
1 July 2021–30 June 2024

REVIEW
1 July 1995–30 June 2021

PLANS
1 July 2024–30 June 2027

CHARMEC

Chalmers Railway Mechanics – a NUTEK/VINNOVA Competence Centre
Chalmers University of Technology

FOREWORD

This Triennial Report documents the organisation, operation, financing, and results of Stage 10 (1 July 2021 – 30 June 2024) for the Swedish National Centre of Excellence in Railway Mechanics, CHARMEC. The presentation also contains a review of previous research activities dating back to the establishment of CHARMEC, which was based on a NUTEK/VINNOVA government grant for the period 1995 – 2005. Pages 94–97 display an overview of all 156 projects that have been (or are being) conducted within CHARMEC, but only the 33 projects active during Stage 10 are accounted for in detail. Some results from the period 1 July 2024 – 31 January 2025 have also been included. The report has been compiled by several contributors, with major efforts from Professor Roger Lundén, Professor Jens Nielsen, and Professor Emeritus Bengt Åkesson.

The layout and typesetting were made by Graphic Designer Tomas Wahlberg, based on Yngve Nygren's original design. Further details on the activities within CHARMEC, as well as digital versions of this and previous triennial reports, are available on the CHARMEC website (www.chalmers.se/charmec).

Gothenburg in June 2025
ANDERS EKBERG
Director of CHARMEC

William Chalmers (1748–1811) from Gothenburg, Director of the Swedish East India Company, bequeathed a large sum of money to the start in 1829 of an industrial school that later became the Chalmers University of Technology

Front cover: Photoelastic experiment illustrating stress fields arising during two-point contact between wheel and rail

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REFLECTIONS FROM THE DIRECTOR

The railway provides exceptional capacity for passenger and freight transports, making it a key part of the transport system. Consequently, the reliability of railway operations is of paramount importance. Delays will spread throughout the railway network, impacting multimodal transportation chains and degrading the reputation of railways. It is not the 90% of trains that are on time that will be remembered, but the 10% that are delayed. Such delays create an uncertainty – will I arrive on time for the meeting, will my parts arrive on time for their assembly? Collectively, these factors diminish the competitive advantage of railways, presenting a significant challenge in attracting new business travelers and high-value goods.

The remedy, of course, is to enhance punctuality. However, this is challenging as operations continue to increase on essentially the same rail network. In such a scenario, the robustness and reliability of railway operations need to be improved without reducing capacity. CHARMEC's contribution in this regard sets out from a railway mechanics perspective. This involves investigating designs and materials that ensure a slower and more controlled degradation. Combined with CHARMEC's research into predicting degradation rates and failure conditions, this supports more precise and efficient maintenance planning. This is further supported by our research related to condition monitoring. Here, key aspects include determining which parameters to monitor and how to use the collected data to quantify current status and predict future degradation. This encompasses establishing limits for both maintenance and safety purposes. These limits must be low enough to ensure safe transportations but high enough to avoid unnecessary traffic disruptions.

To achieve these objectives, we believe it is crucial to have a sufficiently broad range of expertise. In the following report, you can read about the various competencies within CHARMEC. These ultimately boil down to the skills of individual persons both at Chalmers and within CHARMEC's partner organisations. Improving the reliability of the railway system necessitates solutions that integrate these individual competencies. This in turn requires effective communication between researchers, engineers, and other stakeholders to ensure that the research addresses real-world issues in a scientifically sound manner that expands the research frontier. This is particularly important as reliability must be attained while also meeting demands for sustainability, economy, and other factors.

As the railway system has become increasingly complex over the years, there is a need to adopt new approaches. Artificial intelligence (AI) technologies have been used within CHARMEC since the mid-1990s, but with accelerating computational power, AI has now become a mainstream technology. The same applies to areas such as "virtual homologation", "digitalisation", and "digital twins". A key challenge in adopting these technologies is to harness their potential while maintaining focus on the overall objective. For example, AI assessments may need to be complemented with physics-based models to ensure safety.

This Triennial Report provides an overview of our research and how it relates to the overall aims of creating a more reliable, robust, cost-efficient, and environmentally friendly railway system. The following presentations delve into the details of the research, highlighting scientific advancements and their relevance to our primary objective of improving the railway system.

Finally, I would like to extend my gratitude to everyone involved in making the entire chain from research to implementation possible. This includes researchers at CHARMEC, colleagues at our industrial and administrative partners, as well as colleagues at other organisations around the world. Just as a functioning railway system requires all parts to interact, a scientifically sound, relevant, and efficient research community necessitates collaboration and mutual support among all involved. It has been my experience that this is indeed the case in the railway research community. For this reason, I firmly believe that the future of railways, while challenging, is bright.

Main entrance to Chalmers University of Technology with the Student Union building on the right

EXECUTIVE SUMMARY

The Competence Centre Chalmers Railway Mechanics (CHARMEC) was established in July 1995 at Chalmers University of Technology in Gothenburg, Sweden. It had its origin in a small-scale railway mechanics research programme initiated in 1987 at the Department of Solid Mechanics, in collaboration with the company Sura Traction (now Lucchini Sweden). A key factor to the success of CHARMEC has been the long-term commitment of the Swedish Transport Administration Trafikverket (previously Banverket) and the industrial partners. Four of the current ten partners during Stage 10 (including Lucchini) have been involved since 1995, while the remaining six have been engaged for eighteen years or more. Another key factor is the core group of dedicated CHARMEC senior researchers at Chalmers University of Technology.

The Swedish Governmental Agency for Innovation Systems (VINNOVA) organised a third international evaluation of CHARMEC at the end of the Centre's Stage 3. The evaluators concluded that CHARMEC had established itself as an internationally recognised multidisciplinary Centre of Excellence in railway mechanics. No such evaluation has taken place since 2003. However, in 2011, VINNOVA initiated an investigation into the impact CHARMEC has had on the companies that participated in the research centre. CHARMEC and several of our partners contributed to this study. In a report from VINNOVA in 2013, the impact of CHARMEC's research was quantified. It was concluded that "Between 1995 and 2011, CHARMEC has altogether strongly contributed to an economic impact for society and industry that can be estimated to between 1 035 and 1 430 MSEK per year", see page 116 in the Triennial Report for Stage 7.

The annual budget for the three years of Stage 10 (1 July 2021 – 30 June 2024) has been MSEK 33.2 (about MEUR 3.0), see page 90. Three parties have provided funding: Chalmers University of Technology, Trafikverket, and an Industrial Interests Group comprising nine partners. Substantial funding was also provided by the European Union (EU). In total, 19 ordinary research projects, 7 EU projects, and 7 development projects were carried out during Stage 10.

At Chalmers, 36 people (project leaders, academic supervisors, doctoral students and senior researchers) from 3 departments (out of a total of 13 at Chalmers, see page 99) have been involved. They published 90 scientific papers in international journals and conference proceedings and contributed to 11 EU Deliverables during Stage 10. Seven Licentiate degrees and six PhD degrees were conferred during Stage 10.

A total of 70 Licentiate degrees and 60 PhD degrees in railway mechanics have been awarded up to June 2024, see pages 70–71. More than 100 partners (industries, universities, institutes, public agencies, consultancies) from 14 countries have been involved in our European projects during Stage 10.

CHARMEC endeavours to combine academic excellence with industrial relevance, while producing first-rate research and highly skilled PhDs, Licentiates, and MScs. Our work encompasses mathematical modelling, numerical studies, laboratory experiments, and full-scale field measurements. We have collaborated closely with Trafikverket and the Industrial Interests Group to promote implementation. Knowledge transfer has been facilitated through advisory groups, industrial site visits, regular seminars and other meetings, as well as through coauthored journal papers, co-ordinated conference participation and joint field experiment campaigns. Implementation has been further supported by activities, such as directed numerical and experimental studies, assistance in defining regulations and specifications, involvement in collaborative work, support to governmental investigations, etc. Due to the internationalisation of railway regulations, international collaboration has become increasingly important. Here CHARMEC's involvement in EU projects (see page 13) plays a significant role.

Funding (MSEK) of CHARMEC including EU projects

Stage	At start of Stage			At end of Stage		
	Cash	In-kind	Total	Cash	In-kind	Total
1	11.7	8.8	20.5	13.0	8.8	21.8
2	34.8	25.0	59.8	35.0	25.0	60.0
3	38.8	26.2	65.0	46.0	25.7	71.1
4	36.9	28.4	65.3	47.8	27.5	75.3
5	48.5	21.6	70.1	47.1	21.6	68.7
6	45.7	17.2	62.9	49.5	17.2	66.7
7	50.8	16.6	67.4	49.8	18.5	68.3
8	70.6	11.5	82.1	66.9	11.0	77.9
9	68.5	9.0	77.5	73.2	8.4	81.6
10	77.3	8.6	85.9	90.5	9.1	99.6
11	95.1 *	8.4 *	103.5 *			

Note that Stage 1 only lasted two years whereas the following Stages are for three years

The approximate exchange rate (December 2024) is 1 MSEK = 0.09 MEUR

* After Board Meeting on 25 November 2024

INTRODUCTION

CHARMEC is an acronym for *CHA*lmers *R*ailway *MEC*hanics. This Centre of Excellence, or Competence Centre, was established at Chalmers University of Technology in 1995. A formal agreement was reached at the Swedish National Board for Industrial and Technical Development (NUTEK) in Stockholm on 7 July 1995. The funding for Stage 1 (1 July 1995 – 30 June 1997) with a total of MSEK 20.5 was agreed upon by NUTEK, the University and the four partners Banverket, Abetong Teknik, Adtranz Wheelset and SJ Machine Division. Research in railway mechanics began on a small scale at Chalmers Solid Mechanics in 1987, when a first bilateral contract was signed between Bengt Åkesson of that department and Åke Hassellöf of Sura Traction (later ABB Sura Traction and Adtranz Wheelset, and now Lucchini Sweden).

CHARMEC's Stage 2 (1 July 1997 – 30 June 2000) was agreed upon at a meeting in Stockholm on 10 October 1997. Cardo Rail (later SAB WABCO Group and Faiveley Transport Nordic, now Wabtec Faiveley Nordic), Duroc Rail and Inexa Profil joined as new industrial partners. An agreement for CHARMEC's Stage 3 (1 July 2000 – 30 June 2003) was reached at NUTEK's office in Stockholm on 22 June 2000. Adtranz Sweden (later Bombardier Transportation, now Alstom Transportation) then joined the Industrial Interests Group. During Stage 3, Inexa Profil went into receivership and left CHARMEC. As of 1 January 2001, NUTEK's responsibility for CHARMEC was taken over by the Swedish Governmental Agency for Innovation Systems (VINNOVA).

An agreement for CHARMEC's Stage 4 (1 July 2003 – 30 June 2006) was reached at VINNOVA's office in Stockholm on 19 June 2003. Green Cargo AB (a Swedish freight operator), SL Technology (a division of AB Storstockholms Lokaltrafik) and voestalpine Bahnsysteme GmbH & CoKG (an Austrian rail and switch manufacturer) joined as new industrial partners. VINNOVA's funding of MSEK 6.0 per annum was only provided during the first two years of Stage 4. TrainTech Engineering Sweden (later Interfleet Technology, SNCLavalin and Atkins Sverige, now SYSTRA Sverige) replaced SJ Machine Division.

In the Principal Agreement for CHARMEC's Stage 5 (1 July 2006 – 30 June 2009), Banverket was directly included in the agreement and also assigned part of the administrative role that was previously filled by VINNOVA. SJ AB and SweMaint AB joined the Industrial Interests Group during Stage 5. One member, Duroc Rail, left CHARMEC at the end of Stage 4. Jan-Eric Sundgren, President of Chalmers University of Technology, and Karin Markides, the new President from 1 July 2006, signed the contract for Stage 5 on 19 June and 19 September 2006, respectively. The Principal Agreements for Stages 6 (1 July 2009 – 30 June 2012) and 7 (1 July 2012 – 30 June 2015) were constructed in the same form as those for Stages 4 and 5 and involved the same members of the Industrial Interests Group. President Karin Markides signed the contract for Stage 6 on 9 June 2009. As of 1 April 2010, Banverket was merged into the new governmental authority Trafikverket. The contract for Stage 7 was signed by President Karin Markides on 19 June 2012. During Stage 7, SL Technology was transformed into SLL Trafikförvaltningen. The consultancy ÅF joined CHARMEC in 2014 but left at the end of Stage 7, along with SLL.

In the Principal Agreement for CHARMEC's Stage 8 (1 July 2015 – 30 June 2018), the financial terms with Trafikverket were detailed in a separate contract. During Stages 8 and 9, voestalpine was represented by their two companies voestalpine Schienen GmbH and voestalpine VAE GmbH, and during Stage 10 (1 July 2021 – 30 June 2024) by voestalpine Railway Systems GmbH. The contract for Stage 8 was signed by Stefan Bengtsson, President of Chalmers University, on 1 October 2015. The contract for Stage 9 (1 July 2018 – 30 June 2021) was signed by him on 27 August 2018, and the contract for Stage 10 on 16 August 2021. For a brief outline of CHARMEC's Stage 11 (1 July 2024 – 30 June 2027), see page 93. The volume of CHARMEC's activities since its inception is set out in the table on page 6.

The three parties to the agreement on Stage 10 were:

Chalmers University of Technology

Trafikverket
The Swedish Transport Administration (being responsible for the construction, operation and maintenance of all state-owned roads and railways, and also for the development of long-term plans for the transport system on road and railway, at sea and in the air) with its administrative centre in Borlänge

The Industrial Interests Group

Abetong (now Heidelberg Materials Precast Abetong) – *a HeidelbergCement Group* company and concrete sleeper manufacturer headquartered in Växjö

Bombardier Transportation (now Alstom Transportation) – an international train manufacturer with its Swedish headquarters in Västerås

Faiveley Transport Nordic (now Wabtec Faiveley Nordic) – an international manufacturer of braking systems with its Swedish headquarters in Landskrona

Green Cargo – a railway freight operator with its headquarters in Stockholm/Solna

Atkins Sverige (now SYSTRA Sverige) – an international consultancy with its Swedish headquarters in Stockholm/Solna

Lucchini Sweden – a wheelset manufacturer (the only one in the Nordic region) located in Surahammar

SJ – a passenger train operator with its headquarters in Stockholm

SweMaint – a maintainer of freight wagons with its headquarters in Gothenburg (owned by *Kockums Industrier*)

voestalpine Railway Systems – an international manufacturer of rails and turnouts and provider of railway infrastructure solutions, with its headquarters in Leoben (Austria)

VISION AND GOALS

CHARMEC is a strong player among world-leading research centres in railway mechanics and contributes significantly towards achieving lower production, maintenance, operating and environmental costs and to overall improvement in the safety, sustainability and quality of railway transportation. The University, Trafikverket and the Industry collaborate in realising this vision.

CHARMEC successfully combines the identification, formulation and solution of industrially relevant problems with high academic standards and internationally viable research. CHARMEC disseminates its research results and contributes to industrial development and growth in Sweden and abroad.

CHARMEC maintains an up-to-date body of knowledge and preparedness, which can be put to use at short notice in the event of unexpected damage or an accident during railway operations in Sweden or abroad. The scientific level and practical usefulness of CHARMEC's academic and industrial achievements are such that continued long-term support to CHARMEC is profitable for the Government, the University and the Industry.

CHARMEC's specific goals include the national training and examination of MScs, Licentiates and PhDs, and the international presentation and publication of research results. Fundamental and applied research projects are integrated. CHARMEC's industrial partners are supported in the implementation of the solutions that are reached and the use of the tools that are developed. CHARMEC attracts able and motivated PhD students and senior researchers. The MScs, Licentiates and PhDs who graduate from CHARMEC make attractive employees in the railway industry and associated R&D organisations.

CHARMEC's research focuses on the interaction of various mechanical components. Analytical, numerical and experimental tools are developed and applied. New and innovative materials, designs and controls are explored. The life-cycle optimisation of parts and systems for track structure and running gear is intended to slow down the degradation of ballast and embankments, increase the life of sleepers, slabs and pads, improve track alignment stability, reduce rail and wheel wear, reduce the tendency towards rolling contact fatigue of rails and wheels, reduce the levels of vibration and noise in trains, tracks and their surroundings, and improve systems for the monitoring and operation of brakes, bearings, wheels, etc.

BOARD AND DIRECTOR

Professor Martin Nilsson Jacobi, President of Chalmers University of Technology since 1 September 2023, in consultation with Trafikverket and the Industrial Interests Group, appointed the following members of the Board of the Competence Centre CHARMEC at the end of Stage 10 (decision dated 6 February 2024):

Otto Andersson (chair)	Trafikverket
Roger Deuce	Alstom Transportation
Annette Bernström	Green Cargo
Rikard Bolmsvik	Heidelberg Materials
Mikael Rahunen	Lucchini Sweden
Susanne Rymell	SJ
Tilo Reuter	SweMaint
Markus Meinel	SYSTRA Sverige
Melker Pettersson	Trafikverket
Björn Drakenberg	voestalpine Railway Systems
Fredrik Blennow	Wabtec Faiveley
Sebastian Stichel	Royal Institute of Technology (KTH)
Sinisa Krajnovic	Chalmers
Violeta Roso	Chalmers

Otto Andersson was appointed as a member and chairperson of the Board from 1 April 2023. Björn Paulsson of Banverket held this position from the inception of CHARMEC on 1 July 1995 until 31 December 2008. He was succeeded by Tomas Ramstedt (of Banverket / Trafikverket), followed by Annika Renfors (of Trafikverket) from 1 July 2012, and then by Ingemar Frej of Trafikverket from 1 July 2015, who resigned as member and chairperson on 31 March 2023.

Mikael Rahunen of Lucchini Sweden succeeded Erik Kihlberg as a member of the Board on 1 July 2022. On 1 April 2023, Melker Pettersson of Trafikverket joined the Board, and Markus Meinel of SYSTRA Sverige replaced Maria Edén. Also on 1 April 2023, Per Lövsund was succeeded by Sinisa Krajnovic, representing Chalmers Mechanics and Maritime Sciences, and by Violeta Roso, representing Chalmers Area of Advance Transport. On 1 February 2024, Annette Bernström of Green Cargo succeeded Markus Gardbring. From 1 January 2025, Tilo Reuter of SweMaint was replaced by Johan Sjöholm.

Docent (now Professor) Anders Ekberg was appointed Director of CHARMEC from 1 October 2012 (decision by President Karin Markides dated 29 August 2012). The Centre's first Director was Bengt Åkesson, now Professor Emeritus in Solid Mechanics. He was succeeded on 1 April 1997 by Roger Lundén, now Professor in Railway Mechanics at the Chalmers Department of Mechanics and Maritime Sciences, who held the position until 30 September 2012. On 2 September 2024, Lily Boström was employed as administrator of CHARMEC, and she is also CHARMEC's secretary.

BOARD MEMBERS

Otto Andersson
of Trafikverket (Chairperson,
Stages 10+11)

Roger Deuce
of Alstom Transportation
(Stages 9+10+11)

Rikard Bolmsvik
of Heidelberg Materials
(Stages 5+6+7+8+9+10+11)

Mikael Rahunen
of Lucchini Sweden
(Stages 10+11)

Susanne Rymell
of SJ
(Stages 6+7+8+9+10+11)

Tilo Reuter
of SweMaint
(Stages 8+9+10+11)

Johan Sjöholm
of SweMaint
(Stage 11)

Markus Meinel
of SYSTRA Sverige
(Stages 10+11)

Melker Pettersson
of Trafikverket
(Stages 10+11)

Björn Drakenberg
of voestalpine
Railway Systems
(Stages 7+8+9+10+11)

Fredrik Blennow
of Wabtec Faiveley Nordic
(Stages 8+9+10+11)

Sebastian Stichel
of KTH Railway Group
(Stages 7+8+9+10+11)

Sinisa Krajnovic
of Chalmers
(Stages 10+11)

Violeta Roso
of Chalmers
(Stages 10+11)

Anders Ekberg
of Chalmers Mechanics
and Maritime Sciences
(Director of CHARMEC)

Lily Boström
of Chalmers Mechanics
and Maritime Sciences
(Administrator / Secretary)

QUALITY ASSESSMENT AND KNOWLEDGE TRANSFER

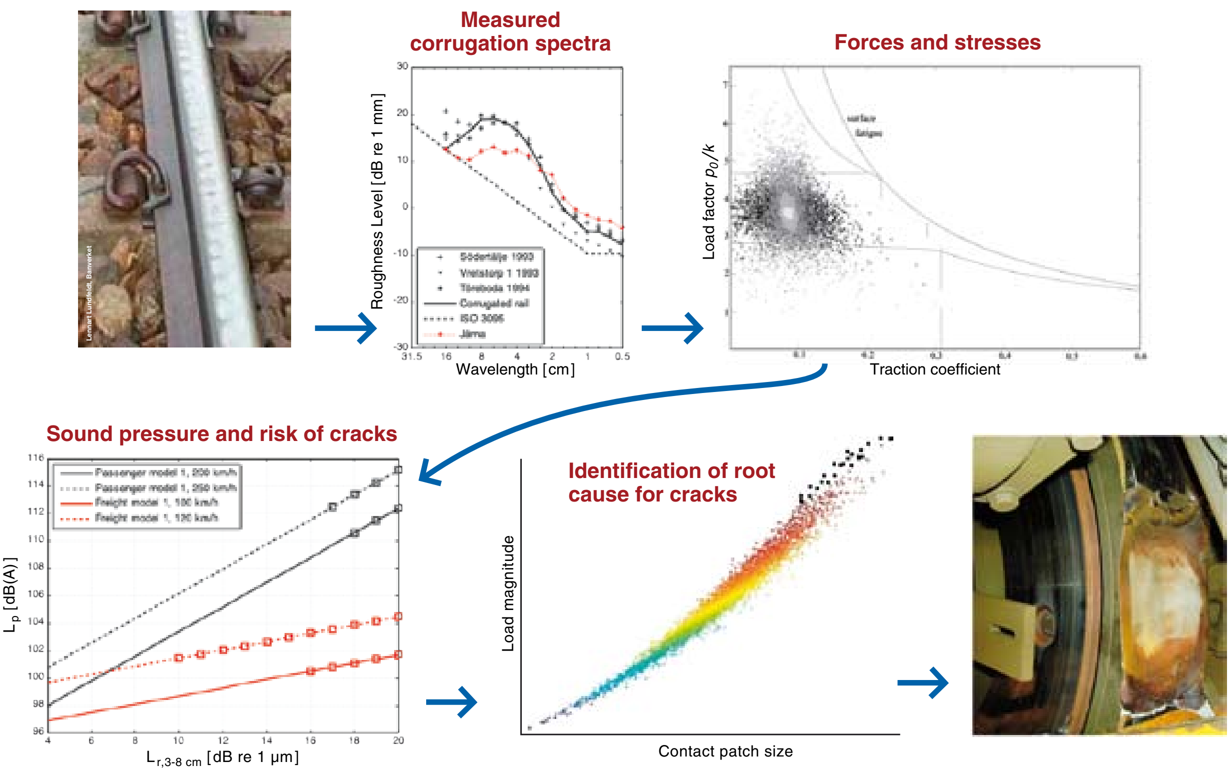
In our opinion, an evaluation of the quality and quantity of the results and impact achieved by a Competence Centre such as CHARMEC should include the following considerations:

- The capacity to understand, formulate, and scientifically address the current problems and long-term challenges faced by Trafikverket and the Industrial Interests Group
- The ability to launch and manage high-quality, future-oriented projects within the Centre's domain of expertise
- The publication of scientific works in recognised peer-reviewed international journals
- The publication of read papers in the proceedings of esteemed international conferences
- The conferring of Licentiate and PhD degrees, along with the appointment of Docents and Senior staff
- The knowledge transfer to Trafikverket and the Industrial Interests Group, including information on achieved results and assistance in implementation of research outcomes
- The development, both nationally and internationally, of the Centre's role as a partner for dialogue, as an information hub, and as a network builder
- The development and maintaining of high-quality postgraduate education in core areas to supply the sector with highly skilled professionals

During Stage 10, the scientific quality of CHARMEC's research results has also been assured through public presentation and criticism at national licentiate seminars and defences of doctoral dissertations.

The relevance of our research has been secured through discussions at Board meetings, seminars, reference group meetings, as well as through industrial visits and guest research exchanges. Additionally, our participation in global railway technology conferences, workshops, and seminars has contributed to the calibration of CHARMEC's research

The transfer of knowledge to Trafikverket and the Industry has been facilitated by means of networking and staff exchanges, co-operative projects, orientation and summarising at seminars, informative reports, and the provision of test results and computer programs. Additionally, hands-on support in key areas has been provided. A significant aspect of this knowledge transfer is the employment of individuals with Licentiate or PhD degrees from the University at Trafikverket or within the Industry, either directly or through consulting companies.



An example of combining simulations and analyses to investigate and solve operational issues: Rail corrugation results in high wheel–rail contact forces and noise emissions. These effects can be quantified through numerical simulations and fatigue analyses. By identifying critical levels, it is possible to establish acceptable levels of corrugation. The analyses could also pinpoint the cause of subsurface-initiated rolling contact fatigue as being due to the high loads rather than the poor contact geometry caused by the corrugation

PROGRAMME AREAS CHARMEC STAGE 10

According to the Principal Agreement for Stage 10, the Competence Centre CHARMEC is to operate within six overarching programme areas, as outlined below. The selection of projects within each area is decided by the Centre's Board. These programme areas for Stage 10 remain consistent with those from Stages 3 through 9.

Programme area 1

Interaction of train and track

Samverkan Tåg/Spår, TS

A rolling train is a mobile dynamic system that interacts, via the wheel–rail interface, with the stationary track structure, which itself is a dynamic system. This interaction is a key area within all railway mechanics research. The mechanisms behind vibrations, noise, and wear depend upon the interplay between the rolling train and the track structure. The activities within this programme area aim to enhance understanding, modelling, and prediction of the dynamic interaction for different types and conditions of trains, tracks, and operations. Analytical, numerical, and experimental methods are used.

Programme area 2

Vibrations and noise

Vibrationer och Buller, VB

A considerable reduction in vibrations and noise from railway traffic is crucial for the future acceptance of this mode of transportation. The generation and propagation of vibrations in trains, tracks, and the environment, as well as the emission of noise, are phenomena that are challenging to address both theoretically and experimentally. The activities within this programme area are directed towards achieving a better understanding of the underlying mechanisms. Advanced analytical and numerical tools, along with well-planned laboratory and field experiments and measurements, are required. The goal is to establish a foundation for effective modifications and countermeasures against vibrations and noise in trains, tracks, and their surroundings.

Programme area 3

Materials and maintenance

Material och Underhåll, MU

Suitable and improved materials for axles, wheels, rails, switches and crossings, pads, sleepers, ballast, slabs, and embankments are prerequisites for good mechanical performance, reduced wear, lower maintenance costs, and an increased technical/economic life of these components. The activities within this programme area focus on analysing existing materials and developing new ones. A knowledge base should be established for the rational maintenance of train and track components. This research requires collaboration among various competencies.

Programme area 4

Systems for monitoring and operation

System för övervakning och Drift, SD

Brakes, bearings, axles, wheels, and bogies are important mechanical components of a train, impacting its operational economy and safety. There appears to be considerable potential for improvement in both passenger and freight trains. New components and innovative methods for enhancing and supplementing existing functions should be explored. A systems approach is emphasised, and the work is conducted in a cross-disciplinary environment, drawing on various academic and industrial competencies, including solid mechanics, machine elements, signal analysis, control theory, computer engineering, and mechatronics.

Programme area 5

Parallel EU projects

Parallella EU-projekt, EU

CHARMEC has represented Chalmers University of Technology as a partner (in Horizon 2020 as a linked third party to Trafikverket) in several EU (European Union) projects in railway mechanics since the Fourth Framework Programme in 1996 up to Horizon 2020, including Shift2Rail and the new programme Europe's Rail, see pages 60 and 85.
All our EU projects are closely related to CHARMEC's ongoing research in programme areas 1, 2, 3 and 4, and CHARMEC contributes to the funding of these EU projects.

Programme area 6

Parallel special projects

Parallella SpecialProjekt, SP

At a meeting on 10 September 2002, the CHARMEC Board decided to gather and list a number of our bilateral agreements and separate research and development projects in railway mechanics under the above heading. This programme area includes both short-term and long-term projects, several of which have been established for the industrial implementation of CHARMEC's research results. The funding originates from several sources, including CHARMEC's partners, VINNOVA, and Chalmers.

SUMMARY OF CHARMEC STAGE 10

Research at the Centre during Stage 10 (1 July 2021 – 30 June 2024) has been carried out as planned. The Board of CHARMEC met as follows:

14 September 2021	15 February 2023
9 December 2021	11 May 2023
16 February 2022	14 September 2023
24 May 2022	28 November 2023
29 September 2022	14 February 2024
30 November 2022	2 May 2024

The meeting on 14 September 2021 was held exclusively online because of the coronavirus pandemic. Subsequent meetings were conducted both in person and online. Detailed minutes were recorded at all meetings. Decisions were made concerning the content and funding of projects carried over from Stage 9, as well as new projects initiated during Stage 10. As all CHARMEC partners are represented on the Board, the Board meetings have served as an efficient combination of working group and decision-making body.

Through interviews with the CHARMEC partners, research needs have been identified and have influenced the Board's decisions regarding the initiation of new projects during Stage 10. Keywords that summarise the views expressed by Trafikverket and the nine companies are:

faster and lighter vehicles / heavier load,
operationally more reliable and robust,
safer, lower life cycle costs, and
environmentally friendlier

The achievement of these goals requires a holistic application of cutting-edge knowledge, methods, and tools across various areas. To this end, collaboration and research exchange within CHARMEC is highly encouraged.

When selecting new projects to be undertaken by CHARMEC, the Board has, in addition to considering the potential for achieving the above objectives, also accounted for the following balances:

fundamental research vs applied research,
doctoral students vs senior researchers,
applicable for the Industry vs
researchable for the University, and
track focus vs vehicle focus

During Stage 6, a committee from the Board adopted a plan in which stakeholders, competencies, visions, strategies, and broad and specific goals were identified. The document "CHARMEC Corporate Plan – Focus Areas" was produced and subsequently updated during Stages 7, 8, 9 and 10. Five Focus Areas, in which CHARMEC has a special capability to contribute, were identified: (i) Rails and running gear, (ii) Switches & crossings, (iii) Sleepers and other types of rail support, (iv) Brake systems, and (v) Vibrations and noise.

Furthermore, CHARMEC will be increasingly involved in implementation-oriented research (see figure).

Chalmers has profiled its research activities into so-called Areas of Advance (*in Swedish: Styrkeområden*). During Stage 10, CHARMEC received financial support from the area Transport.

In 2021, Trafikverket initiated the identification and establishment of so-called Areas of Excellence where key research should be conducted. Important objectives were to recognise synergies, enhance implementation, and identify further research needs. CHARMEC was involved in this work, and our research is now an important part of this initiative, see page 86.

The staff attached to the Centre during Stage 10, both at Chalmers (24 project leaders/principal advisers/senior researchers and 12 doctoral students), at Trafikverket, and within the Industrial Interests Group, have been actively involved. Generally, CHARMEC projects have reference groups, see page 78. Most of these groups consist of members from Trafikverket and the Industrial Interests Group, and they typically meet twice per year. These and other meetings between university researchers and industry representatives have led to an increased involvement in long-term industrial knowledge development and a deeper insight into the working potential of the University. Mutual learning has been achieved.

Seven licentiate theses and six doctoral dissertations in railway mechanics were presented by CHARMEC's doctoral candidates during Stage 10, see pages 70–71. Additionally, 65 articles were published (or accepted for publication) in international scientific journals with a referee system, 25 papers were published in the proceedings of international conferences with a referee system, 11 EU reports were delivered, 11 research reports were edited in our own series of research publications, 5 BSc and MSc theses were edited in our own series of student reports, and several other works were published and presented at minor seminars etc.

As during Stages 1–9, four seminar presentations (or two if held at industrial partners) are typically scheduled in the morning on the days when the Board meets in the afternoon. During these seminars, project leaders / supervisors and doctoral students present and discuss their projects. Since Stage 4, one partner from Trafikverket or the Industrial Interest Group is also scheduled to present their organisations and expectations for CHARMEC. All CHARMEC Board members, project leaders, researchers, and involved persons in the industry (approximately 140 people) are invited to attend these seminars.

Continued participation by CHARMEC researchers in EU projects (Horizon 2020 and Horizon Europe) has enhanced our collaboration with companies, universities, institutes, public agencies, and consultancies across Europe. The CHARMEC network linked to EU projects during Stage 10 comprised more than 100 organisations in 14 countries; see under projects EU21 – EU27. We also co-operate with railway bodies in Australia, Canada, China and Japan.

An indication of the high scientific standards achieved in the activities of the University and the Industry at CHARMEC is the high level of acceptance of articles for journals and contributions to conferences. Approximately 725 such articles and contributions have been published internationally to date. A total of 70 Licentiate degrees and 60 PhD degrees in railway mechanics have been awarded at Chalmers up to June 2024, see again page 70–71.

During Stage 10, the presentations given by partners from Trafikverket or the Industrial Interest Group were:

Uwe Ossberger (online)	voestalpine	14 Sept 2021
Erik Kihlberg (online)	Lucchini	9 Dec 2021
Maria Edén (at Chalmers)	Atkins	16 Febr 2022
Susanne Rymell and Erik Vinberg (in Solna)	SJ	24 May 2022
(CHARMEC's 25th Anniversary)	Chalmers	29 Sept 2022
Maria Edén and Gustav Johansson (in Stockholm)	Atkins	30 Nov 2022
Roger Deuce (at Chalmers)	Alstom	15 Febr 2023
Otto Andersson and Melker Pettersson (in Solna)	Trafikverket	11 May 2023
Tilo Reuter (at Chalmers)	SweMaint	14 Sep 2023
Rikard Bolmsvik (in Vislanda)	Heidelberg	28 Nov 2023
Carina Hultén (at Chalmers)	Trafikverket	14 Febr 2024
Magnus Larsson (in Landskrona)	Wabtec	2 May 2024

PhD student Åsa Fenander (now Åsa Sällström; doctorate earned in 1997) of project TS3 inspecting an instrumented wheelset in the Chalmers Solid Mechanics laboratory

In contrast to previous reports, the Triennial Reports for Stages 8, 9 and 10 only contain details on those projects (now 35) which have been active during the stage. A list of all 156 projects run by CHARMEC during the years 1995–2024 is provided on pages 94–97. The publications listed under the projects have not previously been registered (with the exception of project EU17) in CHARMEC's Biennial and Triennial Reports from 1 July 1995 to 30 June 2021 (Stages 1 through 9), or were incomplete at the time (not yet internationally printed). Several minor reports have been omitted. Internal reports that later resulted in international publication during Stage 10 have also been excluded.

CHARMEC has been involved in European projects since 1996, see page 84. The EU1 – EU14 projects belonged to the European Union's Fourth, Fifth, Sixth and Seventh Framework Programmes. Project EU15 was part of the Horizon 2020 Programme, whereas EU16 – EU21 were part of the Shift2Rail Research and Innovation Action within Horizon 2020. For further details, see the Triennial Report of Stage 9. All these projects are now concluded. However, project EU21 was concluded by the end of 2021 and is reported in the following (and also in the Triennal Report for Stage 9). It should be noted that external access to EU documents supplied by us and others is often limited.

During Stage 10, CHARMEC commenced its involvement in five projects under the Europe's Rail (ER) Joint Undertaking within the Horizon Europe programme (2020– 2027), which is the successor to Shift2Rail. An introduction to Europe's Rail is provided on page 60, followed by detailed reports on our projects EU22–EU27 (with EU23 and EU27 being two parts of the same ER project, IAM4RAIL). Further information on Europe's Rail is given on page 85.

During Stage 10, 35 listed CHARMEC projects are being (or have been) conducted within three departments: Mechanics and Maritime Sciences (abbreviated as M2), Industrial and Materials Science (IMS), and Architecture and Civil Engineering (ACE). The divisions involved within these departments are Dynamics (at M2), Material and Computational Mechanics, and Engineering Materials (both at IMS), and Applied Acoustics (at ACE). For further details, see the organisation chart of Chalmers on page 99.

The project budgets presented for Stage 11 include the sums allocated by the Board up until the meeting on 12 February 2025. The abbreviation Lic Eng, used for the doctoral candidates, stands for the intermediate academic degree Licentiate of Engineering. The abbreviations S2R for Shift2Rail and ER for Europe's Rail are used in some of the budgets.

TS8. INTEGRATED TRACK DYNAMICS

Integrerad spårdynamik

Project leader	Professor Jens Nielsen, Mechanics and Maritime Sciences / Division of Dynamics
Doctoral candidate	None (only senior researcher in this project)
Period	2003-10-01 – 2024-06-30 (– 2027-06-30)
Chalmers budget (excluding university basic resources)	Stage 4: kSEK 2 550 Stage 5: kSEK 1 000 Stage 6: kSEK 300 Stage 7: kSEK 850 Stage 8: kSEK 600 Stage 9: kSEK 761 Stage 10: kSEK 400 Stage 11: kSEK 500
Industrial interests in-kind budget	Stage 4: kSEK 0 + 400 Stage 5: kSEK 50 + 200 Stage 6: kSEK 50 + 100 Stage 7: kSEK 50 + 100 Stage 8: kSEK 100 + 0 Stage 9: kSEK 100 + 0 Stage 10: kSEK 100 + 0 Stage 11: kSEK 100 + 0 *(Heidelberg + Trafikverket)*

For a photo of Jens Nielsen, see page 17

The overall aim of project TS8 is to develop user-friendly computer tools for the rational design of both the whole track system and its individual components. Existing software from CHARMEC projects for the analysis of dynamic vehicle–track interaction, wear and rolling contact fatigue (RCF) of wheel and rail, and railway noise is being extended and integrated. Calculated high-frequency wheel–rail contact forces, rail bending moments, and sleeper bending moments have been validated against measured data. Our in-house computer program DIFF for simulation of high-frequency vertical vehicle–track interaction has been applied in several CHARMEC projects, and it has recently been benchmarked against software developed at Chalmers Division of Acoustics (WERAN) and the Institute of Railway Research at the University of Huddersfield, UK (RailDyn). Examples of performed studies include the analysis of the effects of impact loads generated by wheel flats and rail joints, the design of concrete sleepers for higher axle loads, and the specification of optimum vertical stiffness for ballasted tracks. Part of the project work involves participation in the scientific committee of the International Association for Vehicle System Dynamics (IAVSD), in the international committee of the International Workshop on Railway Noise (IWRN), and in the editorial boards of the periodicals International Journal of Rail Transportation, Railway Engineering Science, and Vehicle System Dynamics.

Jens Nielsen is one of the editors of the book *Noise and Vibration Mitigation for Rail Transportation Systems*, covering the proceedings of the 14th International Workshop on Railway Noise (IWRN14). He has also reviewed papers for the book *Advances in Dynamics of Vehicles on Roads and Tracks*, covering the proceedings of the 28th International Symposium of the International Association for Vehicle System Dynamics (IAVSD2023). He presented an invited state-of-the-art paper on out-of-round wheels and polygonisation in IAVSD2023.

Work carried out in Trafikverket's Area of Excellence 10, Activity 3 'Noise from railway traffic', led by Jens Nielsen of CHARMEC and Peter Torstensson of VTI, has included a survey of ongoing Swedish research in the field of railway noise and vibration, and a national seminar in September 2023 on noise monitoring and control.

The work in project TS8 also includes the planning, preparation, support, and follow-up of research proposals. Examples are the newly launched projects TS23, SP35 and SP37, and contributions to the EU project proposals in Flagship Areas 3, 4 and 5 of Europe's Rail. One aim of project SP35 is to implement a routine in DIFF for the prediction and auralisation of pass-by sound pressure signals radiated from a railway track. Jens Nielsen delivered his annual lecture 'Introduction to track dynamics' at NBIU (Nordisk Banteknisk Ingenjörsutbildning) in Tällberg (Sweden) in March and September 2022, and in September 2023.

Jens Nielsen and Peter Torstensson: Trafikverkets excellensområde 10. Systemperspektiv på järnvägen – Enkätundersökning om buller och vibrationer från spårtrafik (Trafikverket's excellence area 10. A system perspective on the railway – Questionnaire on noise and vibration from railway traffic; in Swedish), Research Report 2022:02, *Chalmers Mechanics and Maritime Sciences*, Gothenburg 2022, 28 pp

Emil Aggestam, Anders Ekberg and Jens Nielsen: Innovative requirements and evaluation methods for slab track design, *IMechE Journal of Rail and Rapid Transit*, vol 238, issue 6, 2023, pp 651-661 (also listed under project EU21) doi.org/10.1177/09544097231218297

Simon Iwnicki, Jens Nielsen and Gongquan Tao: Out-of-round railway wheels and polygonisation, *Vehicle System Dynamics*, vol 61, issue 7, 2023, pp 1787-1830 (invited state-of-the-art presentation at conference *IAVSD2023*) doi.org/10.1080/00423114.2023.2194544

Xiaozhen Sheng, David Thompson, Geert Degrande, Jens Nielsen, Pierre-Etienne Gautier, Kiyoshi Nagakura, Ard Kuijpers, James Nelson, David Towers, David Anderson and Thorsten Tielkes (editors): Noise and Vibration Mitigation for Rail Transportation Systems, *Proceedings 14th International Workshop on Railway Noise (IWRN14)*, Shanghai (China) December 2022. In: Lecture Notes in Mechanical Engineering, *Springer Nature Singapore*, 2024, 824 pp, doi.org/10.1007/978-981-99-7852-6

TS18. NUMERICAL SIMULATIONS OF TRAIN–TRACK DETERIORATION AS A BASIS FOR RAMS AND LCC ANALYSES

Numeriska simuleringar av tågets och spårets nedbrytning som bas för RAMS- och LCC-analyser

Project leader	Docent Björn Pålsson, Mechanics and Maritime Sciences / Division of Dynamics
Doctoral candidate	None (only senior researcher in this project)
Period	2014-03-01 – 2024-06-30 (–2027-06-30)
Chalmers budget (excluding university basic resources)	Stage 7: KSEK 1 000 Stage 8: KSEK 780 (+ 191 in S2R) Stage 9: KSEK 300 (+ 1 749 in S2R) Stage 10: KSEK 200 (+ 2 061 in S2R & ER) Stage 11: KSEK 400 (+ 1 700 in ER)
Industrial interests in-kind budget	Stage 7: KSEK 15 + 50 + 0 + 100 Stage 8: KSEK 0 + 0 + 0 + 0 + 0 Stage 9: KSEK 0 + 0 + 200 + 0 Stage 10: KSEK 0 + 0 + 100 + 0 Stage 11: KSEK 0 + 0 + 100 + 0 *(SL + Trafikverket + voestalpine + ÅF/AFRY)*

For a photo of Björn Pålsson, see page 20

Project TS18 aims to develop methods that can provide high-quality deterioration estimates as input to RAMS (Reliability, Availability, Maintainability and Safety) and LCC (Life Cycle Cost) analyses of railway components. RAMS and LCC are general frameworks that are highly sensitive to the quality of input parameters. The goal is thus to enhance the predictive capabilities of these methods, leading to significant cost reductions for railway operations through improvements in investment and maintenance strategies. To this end, the developed methods should provide robust estimates of deterioration rates for selected components in the railway system as functions of given traffic scenarios. The methods are based on numerical simulations of train–track interaction using multibody simulations (MBS) that can account for the scatter in traffic parameters, such as vehicle type, train speed, wheel and rail profiles, etc.

A framework for the simulation of dynamic interaction between vehicles and switches and crossings (S&Cs) has been established using the commercial multibody simulation code SIMPACK. The framework allows for the automated evaluation of different S&C configurations under load collectives. This is made possible via a parameterised generation of finite element S&C track models, a procedure that enables the realisation of different S&C track designs, for example with different radii or rail profile geometries. The framework also includes damage models for ballast settlement and the deterioration of crossing running surface geometry, allowing for predictions of long-term S&C deterioration. The simulation framework has been developed as part of a greater effort within the EU Shift2Rail projects In2Track, In2Track2 and In2Track3 (our EU17, EU19 and EU21) to develop a so-called Whole System Model (WSM). The purpose of the WSM is to facilitate virtual LCC performance evaluations of S&C designs by combining state-of-the-art simulation models, which aligns with the ambitions of project TS18.

The MBS model in the simulation framework has demonstrated very good agreement with measurement data from an Austrian demonstrator in the In2Track3 project after calibration to the local ballast conditions. The comparison, carried out together with project TS23, involved more than 20 measurement channels, including crossing and sleeper accelerations, bending strains, and sleeper–ballast contact pressures. It also showed good agreement with measurement data when applied to predict crossing geometry deterioration over two years of traffic. The crossing geometry deterioration is predicted using a novel semi-empirical damage model. This model is semi-empirical in that the deterioration modes and damage sensitivities are derived from previous crossing geometry measurements supported by simulations. The damage propagation rate in the simulation is determined by the simulated impact loading.

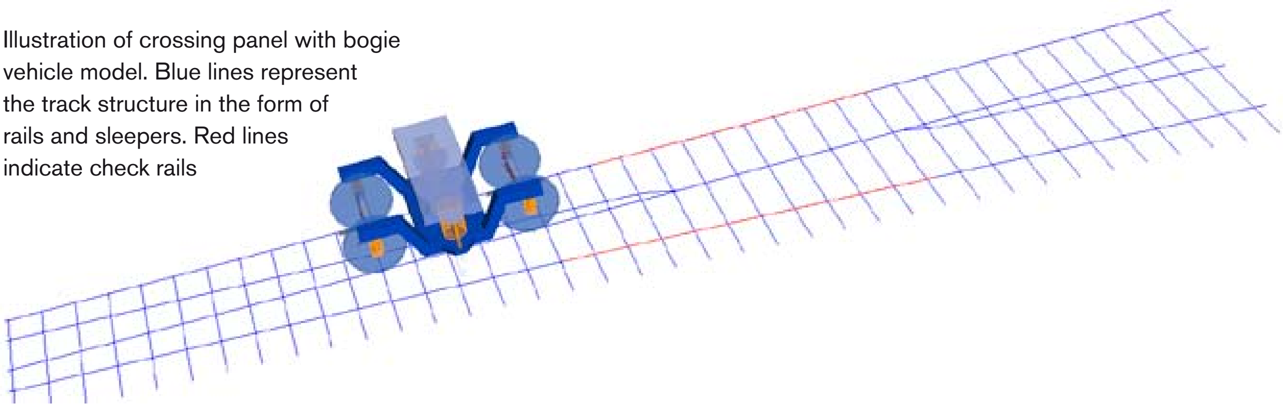
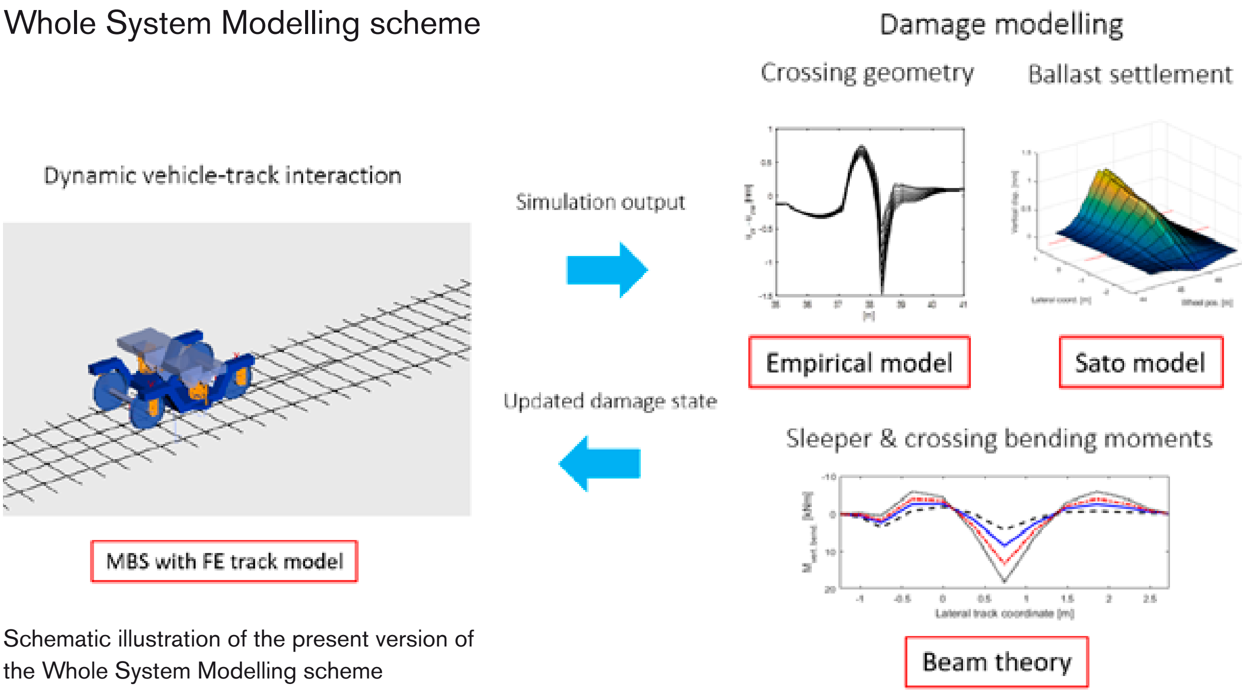


Illustration of crossing panel with bogie vehicle model. Blue lines represent the track structure in the form of rails and sleepers. Red lines indicate check rails

TS18. (cont'd)



Schematic illustration of the present version of the Whole System Modelling scheme

An international S&C simulation benchmark has been organised together with Professor Yann Bezin at the University of Huddersfield in England, as reported in the previous Triennial Report. The outcome of the benchmark has now been published in a special issue of Vehicle System Dynamics, which includes the benchmark statement with input data, as well as results and complementary studies. Project TS18 has collaborated with transport economists at the Swedish National Road and Transport Research Institute (VTI) in efforts to combine economic and engineering analyses to improve maintenance activities. The analyses concern the effects of preventive versus reactive maintenance.

Abderrahman Ait-Ali, Björn Pålsson, Kristofer Odolinski and Peter Torstensson: Evaluation of long-term maintenance of switches & crossings with respect to life-cycle costs and socioeconomic impact, *Proceedings 21st Nordic Seminar on Railway Technology*, Tampere (Finland) June 2022 (Summary and PowerPoint presentation)

Björn Pålsson, Uwe Ossberger and Marko Milosevic: Calibration of a model for dynamic vehicle–track interaction in crossing panels to comprehensive field measurements, *Proceedings Fifth International Conference on Railway Technology (Railways 2022)*, Montpellier (France) August 2022, 5 pp, doi:10.4203/ccc.1.5.4

Björn Pålsson and Yann Bezin: Editorial for S&C benchmark special issue, *Vehicle System Dynamics*, vol 61, issue 3, 2023, pp 639–643, doi.org/10.1080/00423114.2023.2178942

Björn Pålsson, Henrik Vilhelmson, Uwe Ossberger, Michael Sehner, Marko Milosevic, Harald Loy and Jens Nielsen: Dynamic vehicle–track interaction and loading in a railway crossing panel – Calibration of a structural track model to comprehensive field measurements, *Vehicle System Dynamics*, vol 62, issue 11, 2024, pp 2810–2836 (also listed under project TS23) doi.org/10.1080/00423114.2024.2305289

Abderrahman Ait-Ali, Kristofer Odolinski, Björn Pålsson and Peter Torstensson: Evaluating the mix of maintenance activities on railway crossings with respect to life-cycle costs, *European Journal of Transport and Infrastructure Research*, vol 24, issue 1, 2024, 29 pp, doi.org/10.59490/ejtir.2024.24.1.6885

Björn Pålsson and Uwe Ossberger: Whole System Modelling of Switches & Crossings, *Proceedings 22nd Nordic Seminar on Railway Technology*, Stockholm June 2024 (Summary and PowerPoint presentation)

Kristofer Odolinski, Peter Torstensson and Björn Pålsson: Economies of scale and scope in LCC for Switches & Crossings, *Proceedings 22nd Nordic Seminar on Railway Technology*, Stockholm June 2024 (Summary and PowerPoint presentation)

Björn Pålsson and Uwe Ossberger: Prediction of long-term damage evolution in crossing panels using an iterative simulation scheme, *Proceedings Sixth International Conference on Railway Technology (Railways 2024)*, Prague (Czech Republic) September 2024, 12 pp doi:10.4203/ccc.7.6.15

TS20. WHEEL TREAD DAMAGE – IDENTIFICATION AND EFFECTS

Löpbaneskador på hjul – identifiering och konsekvenser

Project leader and supervisor	Professor Elena Kabo, Mechanics and Maritime Sciences / Division of Dynamics
Assistant supervisors	Professor Anders Ekberg, Professor Jens Nielsen and Docent Tore Vernersson, Mechanics and Maritime Sciences
Doctoral candidate	Mr Michele Maglio (from 2018-02-01; Lic Eng October 2020; PhD Jan 2023)
Period	2018-02-01 – 2023-06-30
Chalmers budget (excluding university basic resources)	Stage 8: kSEK 400 (+ 301 in S2R) Stage 9: kSEK 1 200 (+ 1 838 in S2R) Stage 10: kSEK 994 (+ 1 622 in S2R)
Industrial interests in-kind budget	Stage 8: kSEK 0 + 0 + 0 + 0 Stage 9: kSEK 200 + 100 + 100 + 100 Stage 10: kSEK 50 + 100 + 50 + 100 *(Alstom + Green Cargo + Lucchini + Wabtec)*

Wheel tread damage leads to increased wheel–rail contact forces, with magnitudes depending on the type and shape of the geometric irregularity and on the characteristics of the dynamic vehicle–track system. High vertical loads due to wheel tread defects imply an increased risk of wheel fatigue, as well as damage to wheel axles, bearings, and other components. To mitigate the risk of a catastrophic failure of the running gear (and the track), operational limits are imposed on allowed wheel impact loads. Based on field measurements and results from numerical simulations of dynamic vehicle–track interaction, project TS20 has established wheel–rail contact forces and axle stresses resulting from different types of wheel tread damage. Fatigue stress spectra were obtained for the running gear. The influence of tread defects and operational conditions, in particular train speed and track quality, on fatigue damage has been investigated.

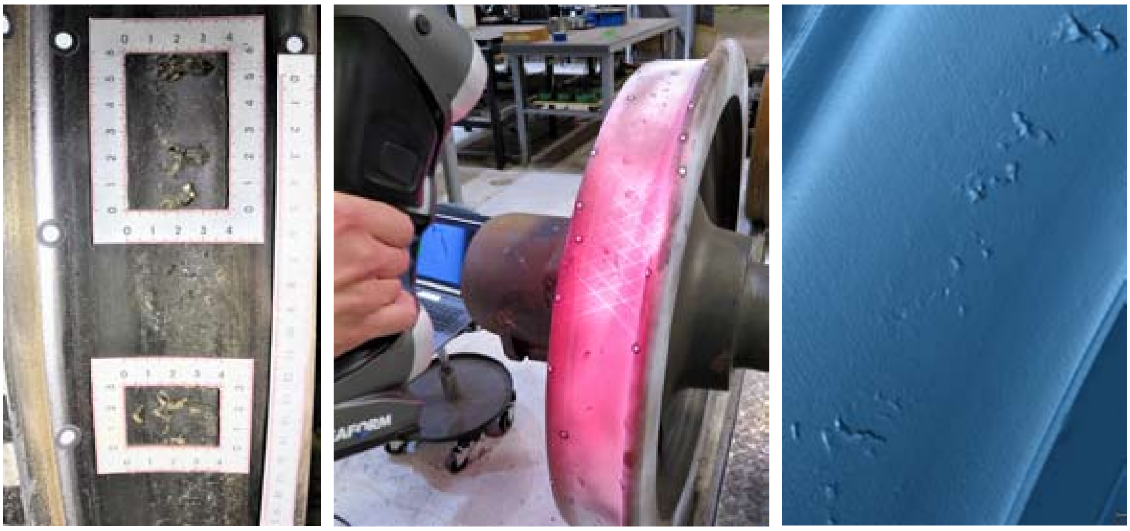
The in-house software WERAN (WhEel/RAil Noise), first developed in project VB10, allows for the computation of wheel–rail contact forces and contact stresses in the time domain. The capability to consider the cross-coupling between the two wheels in a wheelset, as well as between the two rails in the track, has been implemented in the project. Based on post-processing of the calculated contact forces, a numerical procedure to evaluate stresses in the wheelset has also been developed. Some wheels with wheel flats have been scanned using a 3D laser device at the SweMaint workshop in Gothenburg. Both measurement data from Wheel Impact Load Detectors (WILDs) and simulation results from the in-house software WERAN have been studied to assess the impact loads generated by these damaged wheels.

In collaboration with Lucchini RS and SJ, a leading axle of a double-decker X40 train in Sweden has been instrumented with Lucchini's SmartSet® strain gauge-based telemetry to acquire spectra and time histories of axle bending strains. The tread profiles and the out-of-roundness of the wheels mounted on the instrumented wheelset have been measured at regular intervals, while the effect of the evolving tread degradation on wheel–rail contact forces and wheelset stresses has been compared with the long-term telemetry measurements.

A four-week research visit was made to Lucchini RS in Lovere, Italy. During the exchange, Michele Maglio visited the railway wheelset manufacturing lines, the non-destructive testing and product quality departments, the R&D labs, and the railway group at the University of Brescia. The work was mainly focused on the analysis of field data (overloads, stress time histories) collected using the latest implementations of the telemetry system.

PhD student Michele Maglio (right) together with (from the left) Professor Elena Kabo, Docent Tore Vernersson and Professor Jens Nielsen in project TS20. New and worn rail and wheel sections are seen on the table. Michele Maglio is pointing to a wheel running surface with severe RCF damage. Photo taken in 2021

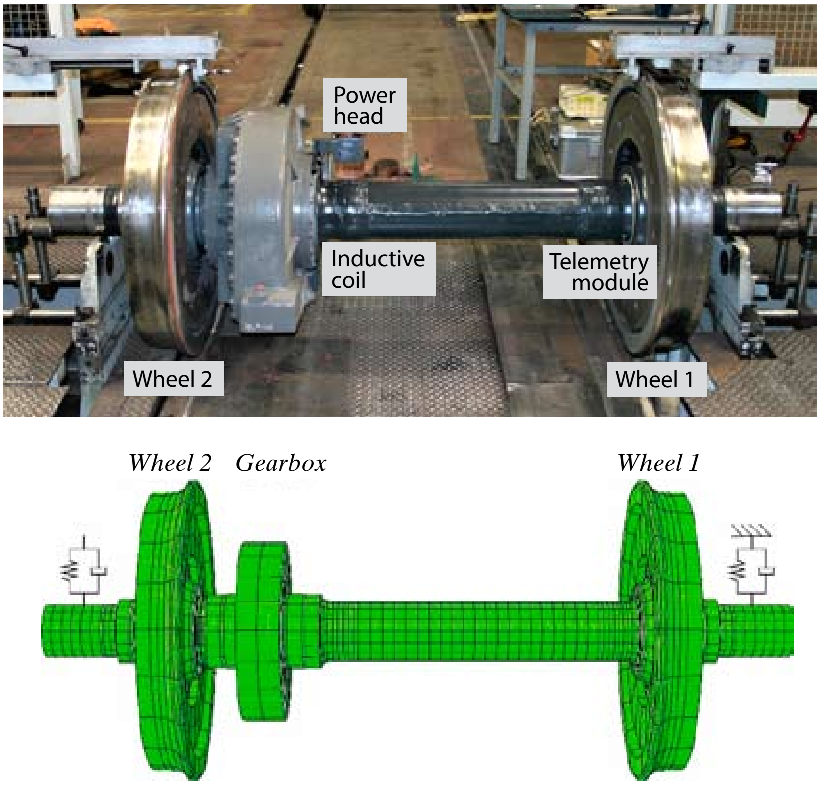
TS20. (cont'd)



Severely damaged wheel of the wheelset studied in the field tests, 3D laser scanning, and surface geometry of a damaged tread surface generated from the scanning

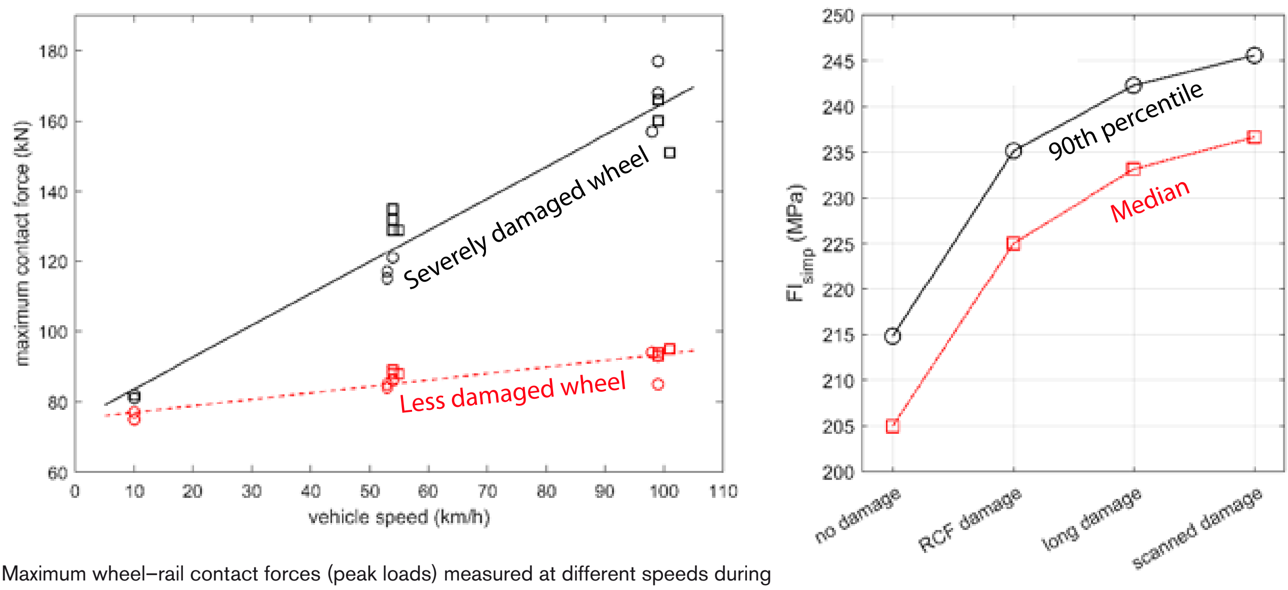
Information regarding the characteristics of different Swedish track sections, in terms of design and surface roughness, has been gathered in collaboration with the Swedish Transport Administration (Trafikverket). Field data, including strain matrices, strain peak values, and time histories from the SmartSet® instrumented axle collected from selected track sections, have been matched to their corresponding track features (number of curves, curve radii, number of switches and crossings, track stiffness, track irregularities, etc). The comparison between track quality data and telemetry measurements has shown that track characteristics for some stretches can be correlated with the occurrence of measured overloads, as well as with the parameters of the statistical distributions that model stress spectra for those stretches.

The scanned surface geometry of a wheel affected by rolling contact fatigue (RCF) damage and wear has been employed in numerical simulations using WERAN. The impact loads simulated in WERAN showed good agreement with the measured magnitudes during a field test. Simulations performed with different shapes of scanned tread damage have shown that longer tread defects have a more



The instrumented wheelset used during the field tests in the SmartSet® part of project TS20 and its finite element model

TS20. (cont'd)



Maximum wheel–rail contact forces (peak loads) measured at different speeds during the field test for a vehicle travelling northbound (circles) or southbound (squares), and derived linear regression models (straight lines). Simplified subsurface fatigue index FI_{simp} estimated for the highest loaded material point of a wheel in the four damage cases

significant influence on wheel–rail impact loads and wheelset stresses than RCF clusters, where the projected surface area of the RCF damage is smaller than (or comparable to) the wheel–rail contact area. The effects these impact load magnitudes induce on the fatigue of bearings and wheel webs, as well as on subsurface-initiated RCF of the wheel tread, have been assessed. Furthermore, the influence of the lateral wheel–rail contact position on the tread, the position of the impact within the sleeper bay, and the vehicle running direction has been studied.

Klara Mattsson from the Master's Programme in Mobility Engineering has completed a MSc-thesis project on impact loads generated by wheel flats on freight wheels. Measured loads from WILDs and numerical simulations have been used in the analyses. The MSc thesis work confirmed that the impact load magnitudes generated by wheel flats depend more on the flat depth than on the flat length. Moreover, it has been shown that the effects of vehicle speed, axle load, and the lateral position of the wheel–rail contact relative to the tread damage are significant.

Michele Maglio successfully defended his doctoral dissertation (see below) on 27 January 2023, with Professor Giorgio Donzella from the University of Brescia in Italy acting as the faculty-appointed external examiner.

Michele Maglio's employment was extended until 30 June 2023, during which time he continued his work in project EU21 (In2Track3). During this period, the review process for the publication of two papers from his doctoral dissertation was completed. Work aimed at predicting axle stress spectra from known track characteristics was continued.

The joint reference group of projects TS20, MU22, MU30, MU35–38, MU40 and MU41 had members from Alstom, KTH, Lucchini Sweden, Trafikverket and voestalpine.

Michele Maglio, Elena Kabo and Anders Ekberg: Railway wheelset fatigue life estimation based on field tests, *Fatigue & Fracture of Engineering Materials and Structures*, vol 45, 2022, pp 2443-2456, doi.org/10.1111/ffe.13756

Michele Maglio, Elena Kabo, Anders Ekberg, Pär Söderström, Daniele Regazzi and Steven Cervello: Prediction of axle fatigue life based on field measurements, *Proceedings 13th World Congress on Railway Research 2022* (WCRR2022), Birmingham (UK) June 2022, 6 pp

Michele Maglio, Elena Kabo and Anders Ekberg: Influence of wheel and rail deterioration on wheelset fatigue life, *Proceedings 21st Nordic Seminar on Railway Technology*, Tampere (Finland) June 2022 (Summary and PowerPoint presentation)

Klara Mattsson: Wheel–rail impact loads generated by wheel flats, MSc Thesis, *Chalmers Mechanics and Maritime Sciences*, Gothenburg 2023, 68 pp and annexes 10 pp odr.chalmers.se/items/0d038923-001e-43dc-9df1-85c688ab82f0

Michele Maglio: Influence of railway wheel tread damage and track properties on wheelset durability – Field tests and numerical simulations, Doctoral Dissertation, *Chalmers Mechanics and Maritime Sciences*, Gothenburg January 2023, 178 pp (Summary and five appended papers) research.chalmers.se/en/publication/533804

Michele Maglio, Elena Kabo and Anders Ekberg: Relating the influence of track properties to axle load spectra through onboard measurements, *IMechE Journal of Rail and Rapid Transit*, vol 238, issue 1, 2024, pp 3-13, doi.org/10.1177/09544097231170086

Michele Maglio, Tore Vernersson, Jens Nielsen, Anders Ekberg and Elena Kabo: Influence of railway wheel tread damage on wheel–rail impact loads and the durability of wheelsets, *Railway Engineering Science*, vol 32, 2024, pp 20-35 doi.org/10.1007/s40534-023-00316-2

TS21. MODEL-BASED CONDITION MONITORING OF S&C

Modellbaserad tillståndsövervakning av växlar och korsningar

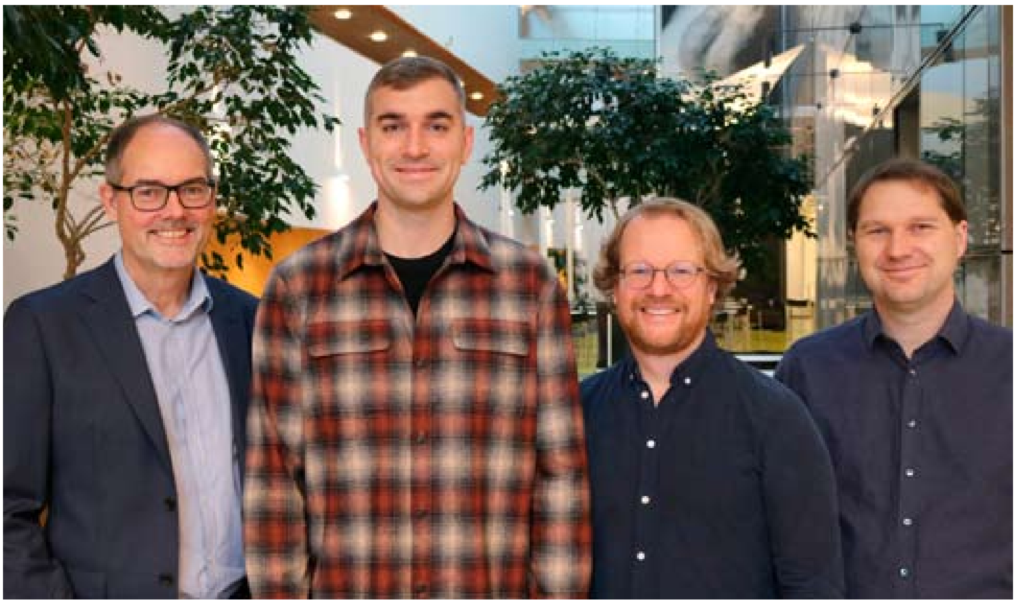
Project leader and supervisor	Docent Björn Pålsson, Mechanics and Maritime Sciences/ Division of Dynamics
Assistant supervisors	Professor Jens Nielsen and Professor Håkan Johansson, Mechanics and Maritime Sciences
Doctoral candidate	Mr Marko Milosevic (from 2019-01-28; Lic Eng June 2021; PhD May 2024)
Period	2018-02-01 – 2023-06-30
Chalmers budget (excluding university basic resources)	Stage 9: kSEK 800 (+ 1 273 in S2R) Stage 10: kSEK 673 (+ 1 102 in S2R)
Industrial interests in-kind budget	Stage 9: kSEK 100 +100 Stage 10: kSEK 50 + 100 *(Heidelberg + voestalpine)*

Crossing panel with accelerometer (yellow box). Image from the Southern Main Line in Sweden

Railway switches and crossings (S&Cs, turnouts) connect different track sections and create a railway network by allowing trains to change between tracks. This functionality comes at a cost as the load-inducing rail discontinuities in the switch and crossing panels cause much higher deterioration rates for S&Cs than for regular plain line track. The high deterioration rates create a potential business case for condition monitoring systems that can enable improved maintenance decisions compared to what can be achieved from periodic inspection intervals using measurement vehicles or visual observation by engineers in track. The objective of project TS21 has therefore been to develop a model-based numerical procedure that can identify the structural condition of S&Cs via embedded sensors.

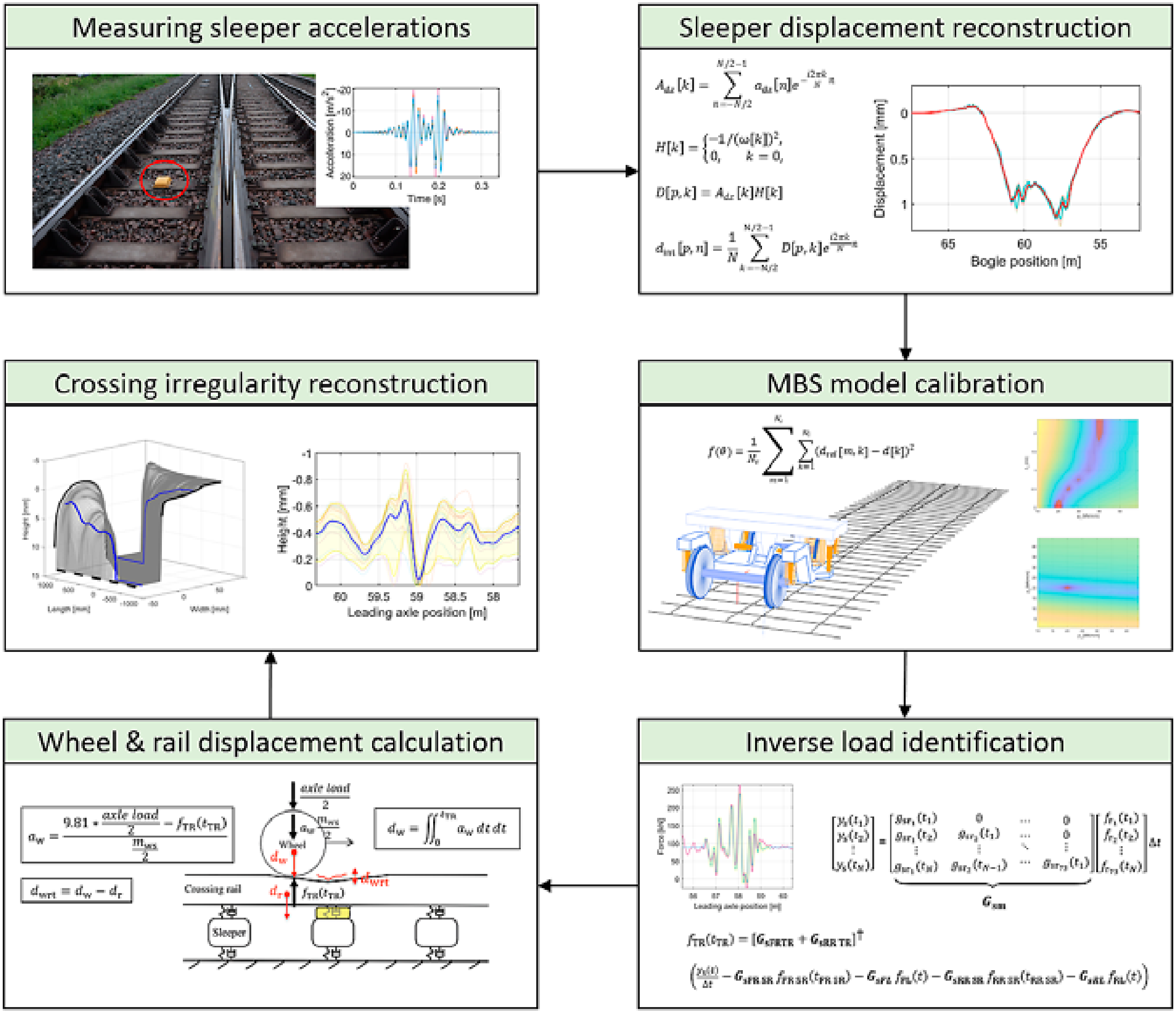
The main outcome of the project is a Crossing Panel Condition Monitoring (CPCM) method focused on the monitoring of two damage modes: the deterioration of crossing rail geometry and of ballast support conditions. A flowchart of the CPCM scheme is presented in the figure. Using measured sleeper acceleration at the crossing transition and knowledge of the crossing type, the CPCM method outputs ballast stiffness, wheel–rail contact forces, and crossing irregularities as condition indicators. By monitoring the evolving indicators, the deterioration of the crossing panel over time can be assessed. Each of the steps in the CPCM is an individual development completed during the project.

Initially, the measured sleeper acceleration is reconstructed to displacement using a technique based on frequency-domain integration and optimisation of the high-pass frequency to remove low-frequency noise. Following this, a multibody simulation model with a FEM structural track model is generated based on knowledge of the nominal parameters for the S&C (radius, rail fastening stiffness, etc). The ballast stiffness properties in the model are then



PhD student Marko Milosevic (second from the left) surrounded by (from the left) Professor Jens Nielsen, Docent Björn Pålsson and Professor Håkan Johansson in project TS21

TS21. (cont'd)



Flowchart for the Crossing Panel Condition Monitoring (CPCM) scheme

calibrated by minimising the difference between the measured and simulated sleeper displacements during a bogie passage. The calibration is performed using the low-pass filtered track displacement to separate the quasi-static global deformation pattern of the track from the dynamic response caused by the current state of the crossing geometry. This allows for the calibration of ballast stiffness without knowledge of the crossing geometry. In the fourth step, the vertical wheel–rail contact forces at the crossing transition are identified from the reconstructed vertical sleeper displacement using a so-called Green's Kernel Function method. Here, the unit impulse responses of the track structure (Green's functions) are used to formulate the relationship between the input force and output sleeper displacement. Based on the estimated wheel–rail contact forces, the wheel and rail displacements during the crossing transition can be computed. In the final step, the relative vertical wheel–rail trajectory, or crossing irregularity for short, that the wheel experiences as it rolls over the crossing transition is computed by taking the difference between the vertical wheel and rail displacements.

The CPCM has been verified and validated using concurrently measured sleeper accelerations and laser-scanned crossing geometries from six crossing panels on the Southern Main Line in Sweden. Good agreement was found between quantities identified from measured data and those from a simulation environment using the scanned crossing geometries. The magnitudes of wheel–rail contact forces and relative wheel–rail trajectories can be directly related to plastic damage and wear evolution rates in a crossing, while the ballast stiffness can be directly related to settlement.

TS21. (cont'd)

Marko Milosevic successfully defended his doctoral dissertation on 24 May 2024 with Professor Luis Baeza from Universitat Politècnica de València (Spain) acting as the faculty-appointed external examiner. The work in project TS21 has been continuously presented and discussed during the biannual workshops with participants from the University of Leoben (Austria), Virtual Vehicle (Austria), voestalpine and CHARMEC. Marko Milosevic participated in the IAVSD2021 and EWSHM 2022 conferences, see below.

Marko Milosevic, Björn Pålsson, Arne Nissen, Jens Nielsen and Håkan Johansson: Condition monitoring of railway crossing geometry via measured and simulated track responses, *Sensors,* vol 22, 2022, 26 pp, doi.org/10.3390/s22031012

Marko Milosevic, Björn Pålsson, Arne Nissen, Jens Nielsen and Håkan Johansson: Demonstration of a digital twin framework for model-based operational condition monitoring of crossing panels, *Proceedings 27th IAVSD Symposium on the Dynamics of Vehicles on Roads and on Tracks* (*IAVSD2021*, online conference), August 2021. In Anna Orlova and David Cole (editors): Lecture Notes in Mechanical Engineering, *Springer Nature Switzerland*, 2022, pp 95-105, doi.org/10.1007/978-3-031-07305-2_11

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Marko Milosevic, Björn Pålsson, Arne Nissen, Jens Nielsen and Håkan Johansson: Inverse wheel–rail contact force and crossing irregularity identification from measured sleeper accelerations – A model-based Green's function approach, *Journal of Sound and Vibration,* vol 589, 2024, 22 pp, doi.org/10.1016/j.jsv.2024.118599

Marko Milosevic: Model-based condition monitoring of railway switches and crossings, Doctoral Dissertation, *Chalmers Mechanics and Maritime Sciences*, Gothenburg May 2024, 186 pp (Summary and six appended papers) research.chalmers.se/en/publication/540937

Iron ore train passing the instrumented transition zone between ballasted track and 3MB slab track at Gransjö in project TS22 (image from movie)

TS22. TRANSITION ZONE DESIGN FOR REDUCED TRACK SETTLEMENTS

Utformning av övergångszoner för minskade sättningar i spår

Project leader and supervisor	Professor Jens Nielsen, Mechanics and Maritime Sciences / Division of Dynamics
Assistant supervisors	Professor Magnus Ekh, Industrial and Materials Science, and Professor Jelke Dijkstra, Architecture and Civil Engineering
Doctoral candidate	Mr Kourosh Nasrollahi (from 2020-10-01; Lic Eng April 2023)
Period	2020-10-01 – 2024-06-30 (– 2025-09-30)
Chalmers budget (excluding university basic resources)	Stage 9: kSEK 350 (+ 400 in S2R) Stage 10: kSEK 1 530 (+ 2 167 in S2R and ER) Stage 11: kSEK 830 (+ 730 in ER)
Industrial interests in-kind budget	Stage 9: kSEK 64 + 0 Stage 10: kSEK 80 + 200 Stage 11: kSEK 50 + 200 *(Heidelberg + voestalpine)*

Transition zones between different track forms, including transitions between different superstructures (e g, slab track to ballasted track) and/or between different substructures (e g, embankment to a bridge or tunnel), are studied. At such transitions, the discontinuity in track structure and the gradient in track stiffness may lead to increased dynamic loads and an evolving vertical irregularity in track geometry due to the accumulation of permanent track deformation (settlement), particularly on the ballasted track side. As a result, frequent and costly maintenance work to rectify the deteriorated geometry may be required. Project TS22 aims to generate models for the simulation of dynamic vehicle–track interaction and long-term settlement, leading to an optimisation of transition zones. Various mitigation measures and designs of the transition zone will be compared, including the use of under sleeper pads (USPs), different sleeper designs and transition wedges.

A model for predicting long-term differential track settlement along a transition zone between two track forms has been developed and calibrated against field measurements. It is used to simulate the development of voided sleepers and the resulting redistribution of foundation loads between adjacent sleepers. The simulation procedure is based on an iterative approach, where a time-domain model of dynamic vehicle–track interaction in the short term is integrated with an empirical model of accumulated ballast settlement in the long term. The non-linear track model is a two-dimensional (2D) finite element model incorporating a seven-parameter mass-spring-damper system for the ballast and subgrade to consider the interaction between adjacent sleepers via the ground. It accounts for state-dependent foundation stiffness and hanging sleepers.

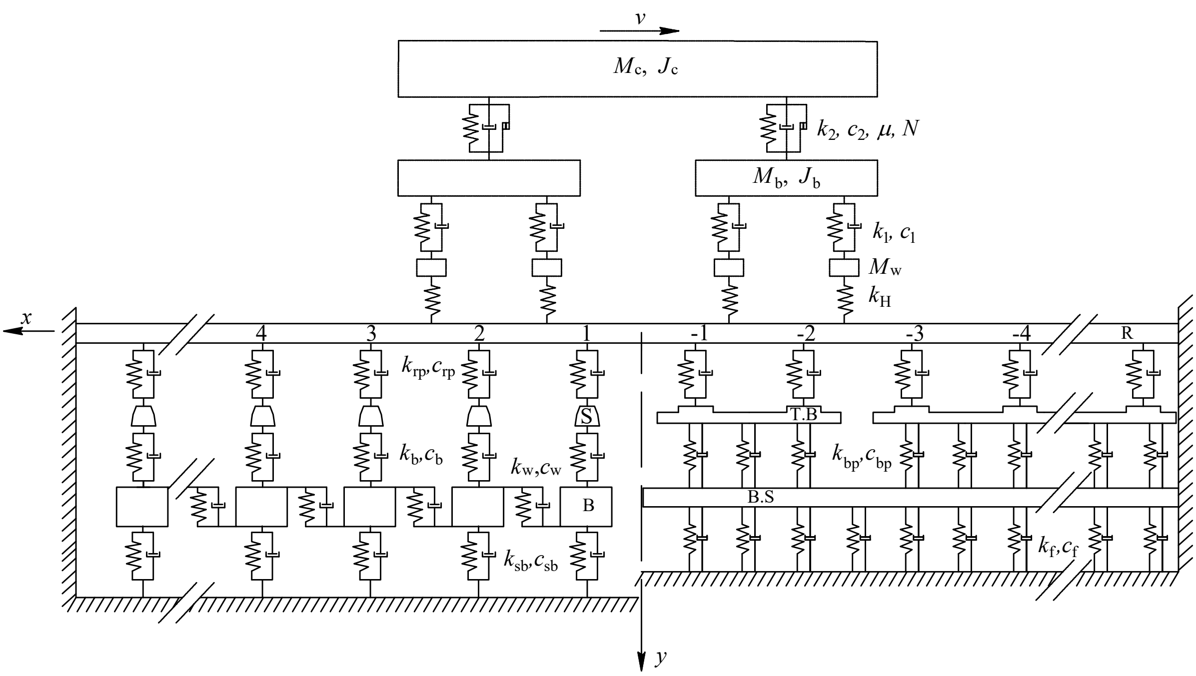
In each iteration step, the calculated load maxima at the interface between each sleeper and the ballast in the ballasted track section, generated by the combination of the gravity load on the track superstructure and the dynamic load from each of the passing wheels of the vehicle model, are used as input to the settlement model. Based on a visco-plastic material model formulation, there is no increment of permanent ballast/subgrade deformation if the maximum sleeper–ballast load is below a certain threshold value. For each sleeper, it is assumed that the current threshold value is dependent on the accumulated settlement at that position. The parameters of the threshold value function are site-specific. It has been shown that the distribution of loads transmitted to the ballast varies along the transition zone. This is due to the stiffness gradient at the transition, but even more so if there is a misalignment in vertical rail level, for example, due to a densification of ballast after the first few load cycles. In both cases, a transient pitching motion of each passing vehicle is generated, contributing to the dynamic loading and, in the long-term, resulting in a local maximum in settlement (a dip in longitudinal level) a few metres from the transition.

PhD student Kourosh Nasrollahi (second from the left) surrounded by (from the left) Professor Magnus Ekh, Professor Jens Nielsen and Professor Jelke Dijkstra in project TS22. Photo taken in 2021

TS22. (cont'd)

Overview of test site at Gransjö involving a transition zone between a ballasted track and a 3MB slab track. Instrumented sleeper with an accelerometer and a displacement transducer

In parallel, an extensive field measurement campaign has been carried out to assess the performance of the transition zone between a ballasted track and a Moulded Modular Multi-Blocks (3MB) slab track in the In2Track3 demonstrator at Gransjö on Malmbanan in northern Sweden. This was achieved by implementing a measurement set-up including four clusters, each with an optical strain gauge array on the rail web, an accelerometer on the sleeper end, and a displacement transducer on the sleeper end. Permanent displacement of the ballast surface was measured in reference to a ground anchor attached to each instrumented sleeper. The measurement set-up was calibrated under quasi-static loading conditions using a known vehicle load. Condition monitoring of the transition zone commenced in September 2022 and continued until June 2023, directly after the installation of the slab track. The short-term dynamic responses of sleeper displacement and rail bending moment, as well as train speed, number of axle passings, and vehicle type, were assessed for each train passage. Furthermore, the long-term evolution of sleeper displacement and rail bending moment was investigated based on continuous measurements over many train passages. Depending on the initial and evolving support conditions for each sleeper and distance from the slab track, considerable differences in measured sleeper



Vehicle and transition zone models. The sleepers (S) are rigid masses supported by a seven-parameter mass-spring-damper representation of the ballast and subgrade with non-linear, and potentially random, stiffness properties

TS22. (cont'd)

displacements (short-term and long-term) were observed. These results were confirmed by at-rest track level measurements using a so-called total station.

A collaboration with Dr Ana Ramos at the University of Porto (Portugal) has resulted in a benchmark where our 2D model and in-house software have been compared with their 3D finite element (FE) model developed in ANSYS. The more extensive 3D model includes a solid FE model of the layered soil foundation, with properties determined from a multichannel analysis of surface waves (MASW) measured at the test site. Both models have been employed to simulate the passage of an iron ore freight vehicle with axle loads of 31.5 tonnes and speed 60 km/h. Good agreement was observed between the measured rail bending moments and sleeper displacements and the corresponding dynamic responses calculated with the 2D and 3D models, with the simulation time being approximately 25 times shorter for the 2D model. Based on the order of 50 iterations with the calibrated 2D model, it was shown that the predicted accumulated settlement for a traffic load of 12 MGT was in good agreement with the in-situ measurements. The collaboration has also resulted in a joint paper, see below, comparing various machine learning models for the prediction of permanent deformation in railway tracks.

The simulation procedure has been demonstrated by investigating the influence of implementing wider sleepers and reduced sleeper spacing in the transition zone as mitigation measures to reduce track stiffness gradient and long-term settlement. Furthermore, it has been shown that the use of USPs reduces track stiffness at rail level, resulting in a wider distribution of load and reduced settlement along the transition zone. In collaboration with a parallel project carried out by PhD candidate Alireza Ahmadi at the Royal Institute of Technology (KTH) in Stockholm, the aim is to integrate our model of vertical dynamic vehicle–track interaction in a transition zone with their 3D discrete element model of ballast and sub-ballast for the prediction of accumulated differential settlement.

This cross-disciplinary project is carried out at Chalmers University as a collaboration between the division of Dynamics at the Department of Mechanics and Maritime Sciences, the division of Material and Computational Mechanics at the Department of Industrial and Materials Science, and the division of Geology and Geotechnics at the Department of Architecture and Civil Engineering. Project TS22 runs in parallel with work in the EU programmes Shift2Rail and Europe's Rail. Kourosh Nasrollahi presented his licentiate thesis (see below) at a seminar on 12 April 2023, where Docent Peter Persson from Lund University introduced the discussion.

Kourosh Nasrollahi, Jens Nielsen, Jelke Dijkstra and Magnus Ekh: Prediction of differential track settlement in transition zones using a non-linear track model, *Proceedings 21st Nordic Seminar on Railway Technology*, Tampere (Finland), June 2022 (Summary and PowerPoint presentation)

Kourosh Nasrollahi, Jens Nielsen, Emil Aggestam, Jelke Dijkstra and Magnus Ekh: Prediction of differential track settlement in transition zones using a non-linear track model, *Proceedings 27th IAVSD Symposium on the Dynamics of Vehicles on Roads and on Tracks (IAVSD2021*, online conference), August 2021. In Anna Orlova and David Cole (editors): Lecture Notes in Mechanical Engineering, *Springer Switzerland*, 2022, pp 282-292 doi.org/10.1007/978-3-031-07305-2_29

Kourosh Nasrollahi, Jelke Dijkstra, Jens Nielsen and Magnus Ekh: Long-term monitoring of settlements below a transition zone in a railway structure, *Proceedings 11th International Symposium on Field Monitoring in Geomechanics (ISFMG2022)*, London (UK) September 2022, Session 8, pp 147–154

Kourosh Nasrollahi, Jens Nielsen, Emil Aggestam, Jelke Dijkstra and Magnus Ekh: Prediction of long-term differential track settlement in a transition zone using an iterative approach, *Engineering Structures*, vol 283, 2023, 16 pp (also listed under project MU39), doi.org/10.1016/j.engstruct.2023.115830

Kourosh Nasrollahi: Differential railway track settlement in a transition zone – Field measurements and numerical simulations, Licentiate Thesis, *Chalmers Mechanics and Maritime Sciences*, Gothenburg April 2023, 108 pp (Summary and two appended papers), research.chalmers.se/en/publication/535010

Kourosh Nasrollahi, Jelke Dijkstra and Jens Nielsen: Towards real-time condition monitoring of a transition zone in a railway structure using fibre Bragg grating sensors, *Transportation Geotechnics*, vol 44, 2024, 14 pp doi.org/10.1016/j.trgeo.2023.101166

Kourosh Nasrollahi, Ana Ramos, Jens Nielsen, Jelke Dijkstra and Magnus Ekh: Benchmark of calibrated 2D and 3D track models for simulation of differential settlement in a transition zone using field measurement data, *Engineering Structures*, vol 316, 2024, 15 pp doi.org/10.1016/j.engstruct.2024.118555

Kourosh Nasrollahi, Jens Nielsen, Jelke Dijkstra and Magnus Ekh: Transition zone design for reduced track settlements, *Proceedings 22nd Nordic Seminar on Railway Technology*, Stockholm June 2024 (Summary and PowerPoint presentation)

Kourosh Nasrollahi and Jens Nielsen: Influence of sleeper base area and spacing on long-term differential settlement in a railway track transition zone, *Proceedings Sixth International Conference on Railway Technology (Railways 2024)*, Prague (Czech Republic) September 2024, 11 pp, doi:10.4203/ccc.7.17.2

Ana Ramos, António Gomes Correia, Kourosh Nasrollahi, Jens Nielsen and Rui Calçada: Machine learning models for predicting permanent deformation in railway tracks, *Transportation Geotechnics*, vol 47, 2024, 16 pp, doi.org/10.1016/j.trgeo.2024.101289

Kourosh Nasrollahi, Ana Ramos, Jens Nielsen, Jelke Dijkstra and Magnus Ekh: Calibration of 2D and 3D track models for simulation of vehicle–track interaction and differential settlement in transition zones using field measurement data, *Proceedings 28th International Symposium on Dynamics of Vehicles on Roads and Tracks (IAVSD2023)*, Ottawa (Canada) August 2023. In Wei Huang and Mehdi Ahmadian (editors): Lecture Notes in Mechanical Engineering, *Springer Nature Switzerland*, 2025, pp 711-720 doi.org/10.1007/978-3-031-66971-2_74

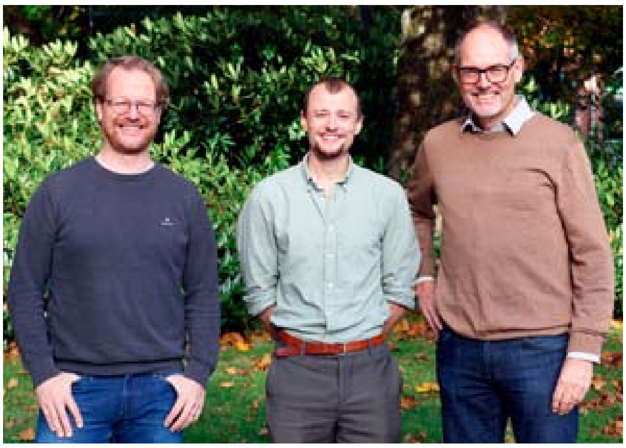
TS23. OPTIMIZATION OF CROSSING PANEL DESIGN FOR IMPROVED LONG-TERM PERFORMANCE

Optimering av korsningspanelens design för bättre långtidsprestanda

Project leader and supervisor	Professor Jens Nielsen, Mechanics and Maritime Sciences / Division of Dynamics
Assistant supervisor	Docent Björn Pålsson, Mechanics and Maritime Sciences
Doctoral candidate	Mr Henrik Vilhelmson (from 2020-08-01; Lic Eng Sep 2024)
Period	2022-08-01 – 2024-06-30 (– 2027-07-31)
Chalmers budget (excluding university basic resources)	Stage 10: kSEK 700 (+ 1 271 in S2R and ER) Stage 11: kSEK 1 995 (+ 1 755 in ER)
Industrial interests in-kind budget	Stage 10: kSEK 77 + 310 Stage 11: kSEK 50 + 200 *(Heidelberg + voestalpine)*

Wheel–rail impact loads generated in railway crossings can lead to severe damage of wheels and rails, and to noise and vibration, rail fatigue due to bending, sleeper cracking and differential settlement of ballast. Project TS23 aims to optimise the design of crossing panels for fixed crossings to improve their long-term performance, while reducing Life Cycle Cost and environmental impact. Particular focus is on specifying the stiffness and damping for the various elastic pads (rail pads, base plate pads, and under sleeper pads) and on the design of rails, base plates, and sleepers. Established codes for crossing panel design and operational regulations are considered in the optimisation process. The robustness of the design will be assessed by evaluating the influence of worn wheel profiles and irregularities in crossing rail geometry and sleeper support conditions.

The beam element model of a railway crossing panel that was developed in projects TS21 and EU21 (In2Track3) has been calibrated using comprehensive field measurements performed in the In2Track2 demonstrator turnout in Austria. This calibration involved introducing and tuning parameters for the void distribution between the crossing transition sleeper and ballast, as well as the stiffnesses for rail fastenings and ballast for the whole crossing panel. The calibration process aimed to minimise an objective function, which was a weighted sum of the root mean square error between measured and simulated displacements, strains, and sleeper–ballast contact forces. To reduce the computational effort, a metamodel of the objective function was generated using a polyharmonic spline. An optimal parameter set was found by applying a gradient-based optimisation algorithm to the metamodel. The results showed good agreement between measured and simulated rail and sleeper displacements, rail and sleeper strains, and distributions of sleeper–ballast contact force within the crossing panel.



PhD student Henrik Vilhelmson surrounded by Docent Björn Pålsson (left) and Professor Jens Nielsen (right) in project TS23

Subsequently, the beam element model has been extended to include a three-dimensional (3D) representation of the crossing. Based on Craig-Bampton reduction, a complete model of the crossing panel has been implemented by assembling individual substructure models for the crossing nose and wing rails (3D elements), sleepers and stock rails (beam elements) in the multibody simulation software SIMPACK. Linear bushings are used for the rail fastenings, and bi-linear bushings for the ballast to account for potentially voided sleepers. The 3D model has been calibrated following the same scheme that was developed for the beam model. It has been shown that the beam model is sufficient to capture the dynamic response of the crossing for frequencies up to about 250 Hz. A comparison between the two models revealed discrepancies in terms of bending stress in the ribs at the bottom surface of the crossing rail. Aside from these stresses, the comparison showed only minor differences in structural response between the two models. However, the 3D model has an increased computational time of about 30% compared to the beam model.

Structural requirements for the optimisation of railway crossing panel design have been proposed. These include dynamic load scenarios established from field measurements, structural load limits for the crossing rail and sleepers, and the maximum allowed vertical contact stress on the ballast surface. The applied load scenarios are established by combining measured data from scanned hollow-worn wheel profiles, scanned crossing nose and wing rail geometries, and sleeper–ballast voids that have been extracted by calibrating a track model to measured sleeper accelerations. Based on the investigated load scenarios, the study shows that the highest dynamic wheel–rail contact loading occurs when a nominal crossing rail geometry (virgin rail

TS23. (cont'd)

profile) is combined with a hollow-worn wheel profile. This provides insight into the field conditions the crossing panel could face before the loading exceeds the load limits of the components. In addition, the comparison highlights the importance of the more detailed 3D model, as the crossing rail stress differs significantly between the models at positions with high stress concentrations. While there is an imbalance in the requirements, with the sleeper load limit generally at higher risk of being exceeded, the limit values are not directly comparable as they are related to different types of failure.

Based on the established structural requirements and dynamic load scenarios, a multi-objective optimisation problem has been formulated. The aim is to reduce the mass of the crossing panel, thereby limiting material use and reducing environmental impact. The height and width of sleepers and the crossing rail are used as design variables. The optimisation problem is solved using a genetic algorithm, and Pareto fronts are generated. Using three different weighting strategies, based on CO_2 emissions, deterioration, and economic cost, the Pareto solutions are evaluated to determine the optimum solutions. The environmental, economic, and deterioration-based weightings exhibit similar trends towards minimising the crossing rail dimensions at the expense of a larger sleeper cross-section. Project TS23 runs in parallel with work in the EU programmes Shift2Rail and Europe's Rail.

Henrik Vilhelmson presented his licentiate thesis (see below) at a seminar on 20 September 2024, where Dr Jou-Yi Shih from ZynaMic Engineering introduced the discussion.

Björn Pålsson, Henrik Vilhelmson, Uwe Ossberger, Michael Sehner, Marko Milosevic, Harald Loy and Jens Nielsen: Dynamic vehicle–track interaction and loading in a railway crossing panel – Calibration of a structural track model to comprehensive field measurements, *Vehicle System Dynamics*, vol 62, issue 11, 2024, pp 2810–2836 (also listed under project TS18) doi.org/10.1080/00423114.2024.2305289

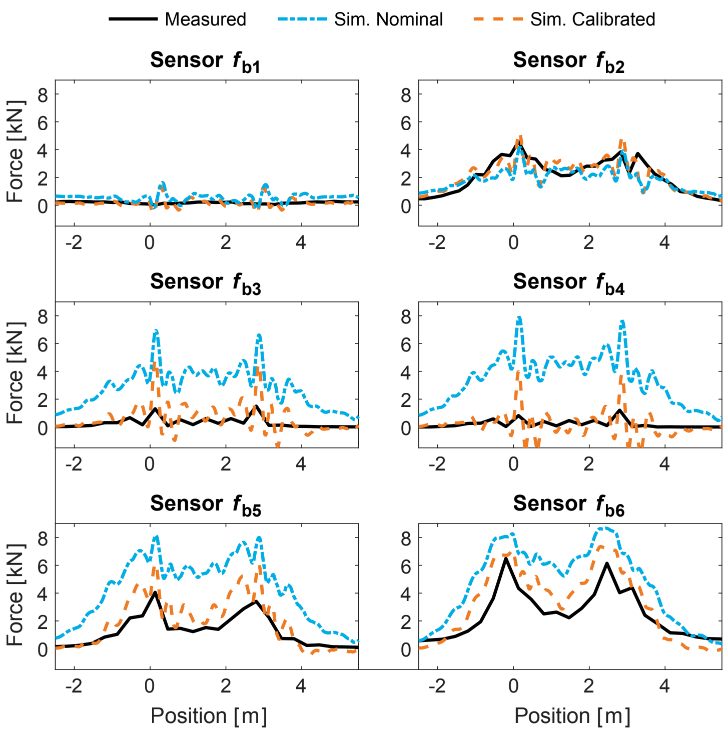
Henrik Vilhelmson, Björn Pålsson, Jens Nielsen, Uwe Ossberger, Michael Sehner and Harald Loy: Dynamic vehicle–track interaction and structural loading in a crossing panel – Calibration and assessment of a model with a 3D representation of the crossing rail, *Vehicle System Dynamics*, vol 62, issue 12, 2024, pp 3168-3190 doi.org/10.1080/00423114.2024.2319275

Henrik Vilhelmson, Björn Pålsson and Jens Nielsen: Optimisation of crossing panel design for reduced environmental footprint, *Proceedings 22nd Nordic Seminar on Railway Technology*, Stockholm June 2024 (Summary and PowerPoint presentation)

Henrik Vilhelmson, Björn Pålsson and Jens Nielsen: Assessment of structural requirements for crossing panel design using dynamic load case scenarios, *Proceedings Sixth International Conference on Railway Technology (Railways 2024)*, Prague (Czech Republic) September 2024, 15 pp, doi.org/10.1007/978-3-031-66971-2_106

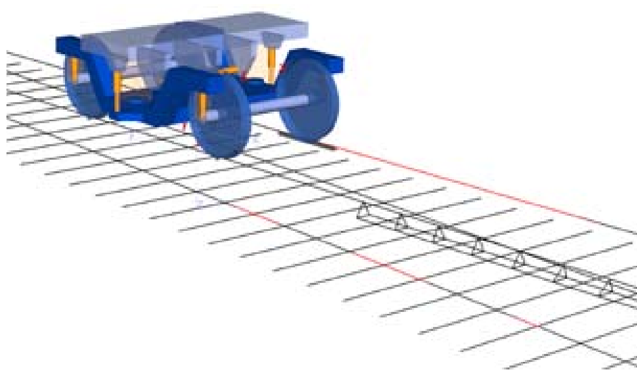
Henrik Vilhelmson: Towards structural design optimisation of railway crossings, Licentiate Thesis, *Chalmers Mechanics and Maritime Sciences*, Gothenburg September 2024, 108 pp (Summary and three appended papers) research.chalmers.se/en/publication/542523

Henrik Vilhelmson, Björn Pålsson, Jens Nielsen, Uwe Ossberger, Michael Sehner and Harald Loy: Development and calibration of a crossing panel model – Comparison of beam and 3D representations of the crossing rail, *Proceedings 28th International Symposium on Dynamics of Vehicles on Roads and Tracks (IAVSD2023)*, Ottawa (Canada) August 2023. In Wei Huang and Mehdi Ahmadian (editors): Lecture Notes in Mechanical Engineering, *Springer Nature Switzerland*, 2025, pp 1028-1036 doi.org/10.1007/978-3-031-66971-2



Time histories of sleeper–ballast contact forces evaluated at six sections of the sleeper under the crossing transition. Nominal and calibrated 3D models of the crossing are compared with measured data. Position 0 m is aligned with the theoretical crossing point (TCP)

Models of vehicle and crossing panel implemented in SIMPACK



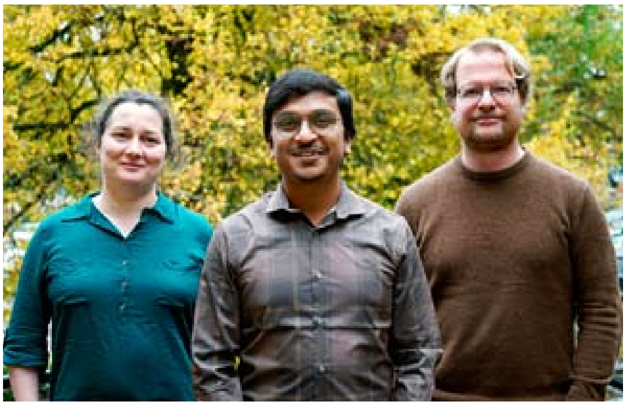
TS24. RISK ANALYSIS FOR DERAILMENT IN SWITCHES

Riskanalys för urspårning i växlar

Project leader and supervisor	Docent Björn Pålsson, Mechanics and Maritime Sciences / Division of Dynamics
Assistant supervisors	Professor Elena Kabo, Professor Anders Ekberg and Dr Björn Paulsson, Mechanics and Maritime Sciences
Doctoral candidate	Mr Sucheth Bysani (from 2022-06-07; Lic Eng Nov 2024)
Period	2022-06-07 – 2024-06-30 (– 2027-06-06)
Chalmers budget (excluding university basic resources)	Stage 10: ksek 1600 Stage 11: ksek 3665
Industrial interests in-kind budget	Stage 10: ksek 200 Stage 11: ksek 200 *(voestalpine)*

The project is financed by Trafikverket (through CHARMEC's budget)

For a photo of Björn Paulsson, see page 80



PhD student Sucheth Bysani surrounded by Professor Elena Kabo and Docent Björn Pålsson in project TS24

The aim of TS24 is to evaluate the possibility of enhancing the reliability of the switch rail control while maintaining safety levels. The focus is on cases where foreign objects (e g, ballast stones, ice, and snow) are trapped between the switch rail and the stock rail, leading to a track gauge reduction that may cause derailment if the object is large and goes undetected by the switch system. A gauge narrowing greater than 15 mm is considered a derailment risk.

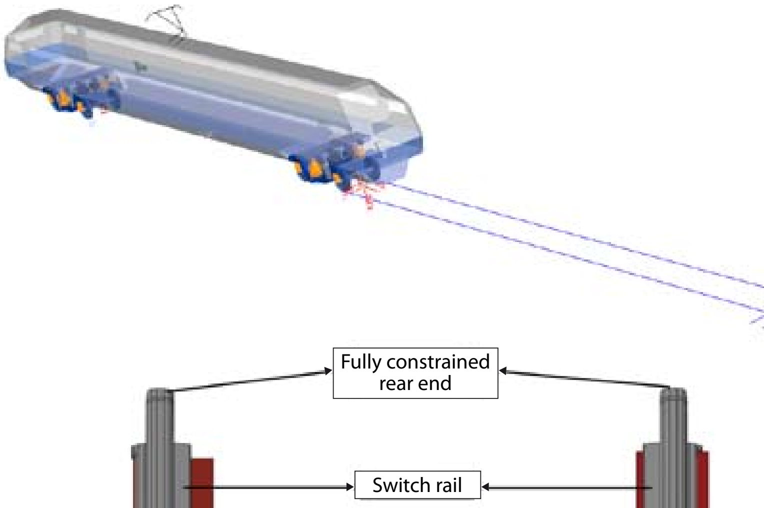
In Sweden, switch rail control sensors (TKKs) are used together with the drives to detect objects that cause this excessive gauge narrowing. According to statistics from the Swedish Transport Administration (Trafikverket), faults in TKKs due to component failure, snow, and foreign object interference account for a significant portion of faults occurring in switches each year. This results in increased maintenance and operational costs, e g, in terms of train delays. Therefore, the present project aims to evaluate the necessity of the TKK sensors by performing simulations of switch operations to provide input to a technical risk analysis of derailments in switches. To this end, finite element (FE) simulations and multibody simulations (MBS) have been carried out to better understand the role of the TKK in detecting foreign objects and the risk of derailment for different types of foreign objects. To obtain model validation data, physical tests on two UIC60-760-1:15 switches have been performed. These tests recorded the deformation of the switch rail when a foreign object was inserted at different locations between the switch and stock rails.

The finite element model was developed to study the influence of foreign objects on switch control. This model includes the two switch rails, their connecting links and the switch rail contact surfaces, see figure. Only those parts of the stock rail that may be in contact with the switch rail are modelled, and they are represented by rigid support surfaces. The links are made from long cylindrical bars connected to the switch rails with pivoting bolt connections. In the model, they are simplified into linear springs. The drive forces are applied as point forces acting in the lateral direction on the foot of the switch rail. A trapped foreign object is modelled as a prescribed displacement in the lateral direction at the foot of the switch rail. When comparing the simulation model to field measurements, it was found that the links are essential to obtain good agreement with measurements and a correct deformation pattern for the switch rails. The validated model was employed in a parametric investigation to study the influence of the position and size of a foreign object on switch rail control. When the TKK was omitted, cases of excessive gauge narrowing with drives in control were found. It can therefore be concluded that the TKKs are necessary to detect gauge narrowing above 15 mm due to foreign objects.

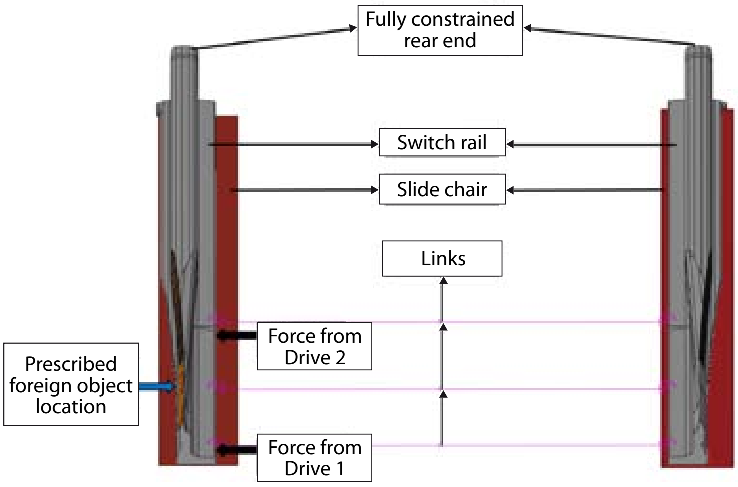
The consequences of removing the TKKs have been investigated. The risk of derailment was evaluated for scenarios where a train passes through a switch with a trapped foreign object between the switch and stock rails, causing a local gauge narrowing. Here, a multibody simulation model was developed to simulate dynamic vehicle–switch interaction while accounting for the properties of the foreign object, see figure. Non-linear models representing crushable ballast stones and linear models representing (practically) uncrushable objects were investigated. The derailment risk was evaluated using a wheel lift criterion, where a wheel lift of more than 6 mm is considered to constitute a significant derailment risk. Furthermore, a parameter study was

TS24. (cont'd)

MBS model in SIMPACK with full vehicle and switch to evaluate derailment risk



Swedish TKK sensor installed in a switch



FE model of the simulated switch rails with three connecting links

performed to investigate the influence on derailment risk of axle load, wheel–rail friction coefficient, and train speed. It was found that a lower axle load, an increasing speed, and a higher wheel–rail friction coefficient increase the risk.

The next step in the project will be to evaluate the probability of foreign objects getting stuck in a switch that are not crushable by the oncoming train and thus could result in derailment. Following this, efforts will be directed towards enhancing current monitoring methods to potentially replace or omit the TKK from switch design. This could, e g, be achieved by adjusting the number or positioning of drives, or by integrating advanced sensors into the switch drives. Additionally, methods to identify the type and size of trapped foreign objects in switches will be explored.

Sucheth Bysani presented his licentiate thesis (see below) at a seminar on 15 November 2024, where Associate Professor Matti Rantatalo from Luleå University of Technology introduced the discussion.

Sucheth Bysani, Björn Pålsson, Elena Kabo and Björn Paulsson: The influence of trapped foreign objects on railway switch control investigated by simulations and field tests, *Chalmers Mechanics and Maritime Sciences*, Gothenburg 2024, 20 pp (submitted for publication)

Sucheth Bysani, Björn Pålsson and Elena Kabo: Multibody simulation of derailment risk in railway switches due to gauge narrowing caused by foreign objects, *Chalmers Mechanics and Maritime Sciences*, Gothenburg 2024, 24 pp (accepted for publication in *Vehicle System Dynamics*)

Sucheth Bysani and Björn Pålsson: Multibody simulation of derailment risk in railway switches due to switch rail irregularities caused by foreign objects, *Proceedings 28th International Symposium on Dynamics of Vehicles on Roads and Tracks (IAVSD2023)*, Ottawa (Canada) August 2023. In Wei Huang and Mehdi Ahmadian (editors): Lecture Notes in Mechanical Engineering, *Springer Nature Switzerland*, 2025, pp 1019-1027 doi.org/10.1007/978-3-031-66971-2_105

Sucheth Bysani, Björn Pålsson, Elena Kabo and Anders Ekberg: Risk of derailment due to entrapped foreign objects in railway switches, *Proceedings 22nd Nordic Seminar on Railway Technology*, Stockholm (Sweden) June 2024 (Summary and PowerPoint presentation)

Sucheth Bysani, Björn Pålsson, Elena Kabo and Björn Paulsson: Investigating the impact of foreign objects on railway switch control – Numerical simulations and field measurements, *Proceedings Sixth International Conference on Railway Technology (Railways 2024)*, Prague (Czech Republic) September 2024, 10 pp doi:10.4203/ccc.7.6.14

Sucheth Bysani: Influence of foreign objects on derailment risks in railway switches, Licentiate Thesis, *Chalmers Mechanics and Maritime Sciences*, Gothenburg November 2024, 72 pp (Summary and two appended papers) research.chalmers.se/en/publication/543406

TS25. DIGITAL TWINS FOR EFFICIENT MAINTENANCE OF SWITCHES & CROSSINGS

Digital tvilling för effektivt underhåll av spårväxlar

PhD student Karl Norberg in project TS25

This doctoral project commenced early in Stage 11, and only a brief report is provided here. Mr Karl Norberg was employed as a PhD student in the project on 19 August 2024. Docent Björn Pålsson of Chalmers Mechanics and Maritime Sciences, and Docent Peter Torstensson and Dr Kristofer Odolinski of VTI (The Swedish National Road and Transport Research Institute) are his supervisors. The aim of project TS25 is to develop a prototype of a digital twin with life cycle cost (LCC) optimisation for more efficient maintenance of switches and crossings (S&C). The long-term deterioration and the coupling between different deterioration mechanisms vary between S&Cs due to differences in design, traffic conditions, and environment (e g, geotechnical substructure, climate, etc), resulting in different maintenance needs. To minimise the LCC of an individual S&C, an individual assessment is therefore needed for maintenance or reinvestment decisions. The digital twin in this case is a virtual representation of a physical system, where condition data and maintenance history are combined with simulation models to identify and predict the condition of an S&C. The target method includes the modelling and simulation of physical and economic aspects of an S&C's life cycle, as well as the analysis of condition monitoring data and maintenance history using a holistic approach.

Scanning of crossing rail at night at Western Main Line in Sweden

VB12. HIGH-FREQUENCY WHEEL–RAIL INTERACTION

Samverkan tåg–spår vid höga frekvenser

Project leader	Docent Astrid Pieringer, Architecture and Civil Engineering / Division of Applied Acoustics
Co-workers	Dr Jannik Theyssen, Architecture and Civil Engineering Docent Peter Torstensson, VTI / Mechanics and Maritime Sciences
Doctoral candidate	None (only senior researchers in this project)
Period	2012-01-01 – 2024-06-30 (– 2027-06-30)
Chalmers budget (excluding university basic resources)	Stages 7, 8, 9, 10 and 11: see below
Industrial interests in-kind budget	Stage 7: kSEK 100 + 25 + 15 + 50 Stage 8: kSEK 100 + 0 + 15 + 0 Stage 9: kSEK 50 + 0 + 20 + 0 Stage 10: kSEK 100 + 0 + 40 + 0 Stage 11: kSEK 100 + 0 + 30 + 0 *(Alstom + SL + SYSTRA + Trafikverket)*

During Stages 7 and 8, this post-doc project was financed partly by the Department of Civil and Environmental Engineering (now ACE) and partly by the Chalmers Area of Advance Transport, profile Sustainable Vehicle Technologies. During Stage 9, it was partly financed by a Marie Skłodowska-Curie Individual Fellowship and Shift2Rail. During Stage 10, it was financed by Shift2Rail (In2Track3) and Trafikverket. During Stage 11, it is partly financed by Trafikverket and Europe's Rail.

The interaction between wheel and rail is the predominant source of noise emission from railway operations across a wide range of conventional train speeds. This wheel–rail noise comprises rolling noise and impact noise caused by vertical interaction, excited by roughness and discrete irregularities on the wheel and rail running surface, respectively. Additionally, it includes squeal noise generated by tangential interaction. In the previous doctoral project VB10, the model WERAN (WhEel/RAil Noise) was developed for the combined vertical and tangential wheel–rail interaction, and it is valid in the frequency range relevant for noise generation. Project VB12 is a continuation of VB10 and focuses on different aspects of high-frequency wheel–rail interaction.

Work on curve squeal has included both simulations with WERAN and field measurements to gain insight into squeal characteristics and influencing parameters. Particular focus has been placed on the influence of track design and maintenance status on the occurrence of curve squeal.

Rolling noise measurements at the demonstrator of the 3MB slab track on the Iron Ore Line in northern Sweden in May 2023

The WERAN curve squeal model has been extended from quasi-static to transient curving and connected to a SIMPACK model for low-frequency vehicle dynamics. This approach allows for the consideration of realistic curving scenarios. The application of the extended model demonstrated that time-varying contact parameters, such as contact position, lateral creepage and friction coefficient, can lead to an onset and offset of squeal. The history of wheel/rail dynamics can also influence the occurrence of squeal and the selection of the squeal frequency.

In work led by VTI (Docent Peter Torstensson and Dr Olle Eriksson) and being financed by Trafikverket (TRV 2020/49829), a statistical analysis of onboard noise monitoring data from the Stockholm metro was carried out, including a total of 379 776 vehicle passages through 143 curves, both inside and outside tunnels. Squeal noise occurrence was analysed with respect to, among other factors, curve radius and rail grinding. The analysis showed that curve squeal has a generally higher probability in smaller radius curves, but this effect levels off at around a 600 m radius and above. It also indicated an increased probability of curve squeal after rail grinding.

To verify WERAN in a real context, simulations were carried out with the combination of SIMPACK and WERAN to qualitatively replicate the results from the statistical analysis for a C20 vehicle on BV50 track in curves with varying radii. As in the statistical analysis, the simulations showed an increased tendency for squeal in smaller radius curves. During rail grinding, the rail profile is ideally restored to the nominal profile and rail corrugation is thereby removed. Both effects could be the reason for an increased probability of squeal in the weeks and months after grinding. For the simulations, only one measured worn rail profile was available, which did not change the squeal tendency compared to a nominal profile. However, it could be shown that a changed lateral contact position (as a result of the

VB12. (cont'd)

changed rail profile and removal of rail corrugation) can lead to the onset and offset of squeal. This could explain the influence of rail grinding on squeal occurrence.

To assess the influence of rail pad stiffness on curve squeal, simulations were performed using a discretely supported rail with soft, medium or stiff rail pads. Medium and stiff rail pads resulted in higher squeal amplitudes compared to the soft rail pad. However, as this parameter study was relatively small, further investigations are necessary before a general conclusion can be drawn about the influence of rail pad stiffness on squeal occurrence and amplitudes.

As a basis for a further investigation of squeal in the Stockholm metro, wayside noise measurements were carried out in a 213 m radius curve over a few hours. This study showed squeal noise emission with an intermittent character for all vehicle passages, with dominant frequencies in the range between 6.3 and 15.8 kHz. This frequency content is significantly higher than what has been concluded from the main body of field measurements presented in the literature. Onboard noise measurements in the same curve over approximately one year revealed squeal from both inner and outer wheels. Together with measurements of frequency response functions of the track and of damped wheelsets from a C20 train, these data will be used to further verify the WERAN model under real conditions and to investigate the influence of track parameters on squeal.

In the Shift2Rail project In2Track3, a demonstrator of a new type of slab track, the '3MB', developed by the company Acciona and originally devised in the FP7 Capacity4Rail project, was installed on the Iron Ore Line in northern Sweden near Gransjö. In May 2023, pass-by noise measurements of in-service trains were conducted at the demonstrator and an adjacent ballasted track section to assess the vibroacoustic performance of the 3MB. In addition to the pass-by measurements, a detailed characterisation of track dynamics and rail roughness was carried out. The analysis of the measurement data showed an increase in equivalent pass-by sound pressure levels at the slab track compared to the ballasted track, with an average increase of about 2 dB observed at 7.5 m from the track. Trains with high sound pressure levels showed lower differences between the two track types, suggesting a possible dominance of wheel radiation in these cases.

WERAN was adapted to the conditions at the measurement site, and a satisfactory agreement was found between measurements and simulations for track mobilities and track decay rates, as well as for the rail acceleration differences between the slab track and ballasted track sections. Simulation results suggest that the somewhat higher rail roughness at shorter wavelengths in the slab track section was not the reason for the increase in the rail component of the total sound pressure level in the slab track section, which can instead be attributed to the differences in track dynamics.

Astrid Pieringer and Wolfgang Kropp: Model-based estimation of rail roughness from axle box acceleration, *Applied Acoustics*, vol 193, 2022, 13 pp, doi.org/10.1016/j.apacoust.2022.108760

Olle Eriksson, Peter Torstensson, Astrid Pieringer, Rickard Nilsson, Martin Höjer, Matthias Asplund and Anna Świerkoska: Statistical analysis of curve squeal based on long-term onboard noise measurements, *Proceedings 21st Nordic Seminar on Railway Technology*, Tampere (Finland) June 2022 (Summary and PowerPoint presentation)

Astrid Pieringer and Peter Torstensson: Verification of a transient model for the simulation of curve squeal on the basis of onboard noise monitoring data from Stockholm metro, *Proceedings Fortschritte der Akustik – DAGA 2023*, 49. Jahrestagung für Akustik, Hamburg (Germany) March 2023, pp 693–696 pub.dega-akustik.de/DAGA_2023/data/articles/000540.pdf

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Jannik Theyssen and Astrid Pieringer: Comparative rolling noise measurements on two railway track types in northern Sweden, Technical report, *Chalmers Architecture and Civil Engineering / Applied Acoustics*, 2024, 78 pp

Astrid Pieringer and Jannik Theyssen: Model-supported analysis of comparative rolling noise measurements on two types of railway tracks, *Proceedings of InterNoise 2024*, Nantes (France) August 2024, 12 pp

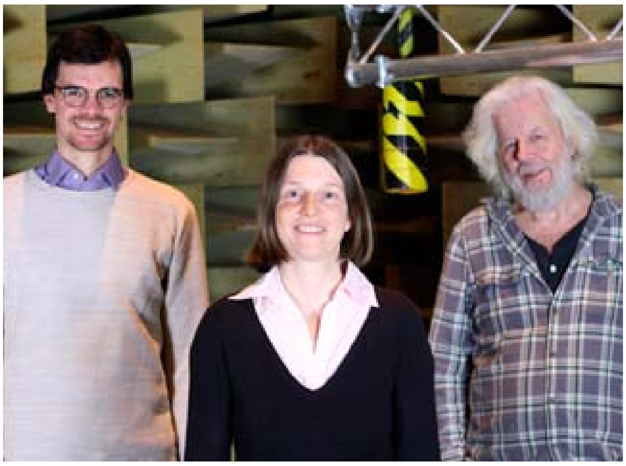
Astrid Pieringer and Jannik Theyssen: Railway rolling noise on a new type of slab track – Field measurements and simulations, *Proceedings DAGA 2024*, Hannover (Germany) March 2024 (Summary and PowerPoint presentation)

Peter Torstensson, Astrid Pieringer, Martin Höjer, Rickard Nilsson and Victor Simonsson: A case study of railway curving noise accounting for squeal generated from both the outer and inner wheel, *Applied Acoustics*, vol 228, 2025, 10 pp doi.org/10.1016/j.apacoust.2024.110327

VB13. PREDICTION AND MITIGATION OF NOISE FROM VEHICLES ON SLAB TRACKS

Prediktering och reduktion av buller från fordon på ballastfria spår

Project leaders and supervisors	Professor Wolfgang Kropp and Dr Astrid Pieringer, Architecture and Civil Engineering / Division of Applied Acoustics
Doctoral candidate	Mr Jannik Theyssen (from 2017-08-28; Lic Eng June 2020; PhD December 2022)
Period	2017-08-28 – 2022-12-31
Chalmers budget (excluding university basic resources)	Stage 8: kSEK 833 Stage 9: kSEK 1 668 (+ 1 065 in S2R) Stage 10: kSEK 930 (+ 714 in S2R)
Industrial interests in-kind budget	Stage 8: kSEK 0 + 0 Stage 9: kSEK 100 + 150 Stage 10: kSEK 50 + 50 *(Alstom + Heidelberg)*



From the left: PhD student Jannik Theyssen (now Doctor), Dr Astrid Pieringer (now Docent) and Professor Wolfgang Kropp in project VB13. The photo was taken in the anechoic chamber at the Division of Applied Acoustics in 2021

Rolling noise from high-speed trains can necessitate costly mitigation measures along the tracks. Therefore, it is crucial to predict rolling noise with high accuracy already in the planning phase. Typically, the Nord2000 prediction tool is used in Scandinavia, but the European prediction model CNOSSOS might also be applied. However, these models are entirely dependent on realistic input for source characterisation. Currently, very little data is available for rolling noise on slab tracks. At the same time, it is known that rolling noise on slab tracks can be noticeably higher than on traditional ballasted tracks.

The overall objective of project VB13 was to develop a method for accurately predicting rolling noise at high speeds on slab tracks and assessing the impact of noise control measures on noise levels along the track. This is essential for identifying cost-effective and sustainable means for noise reduction. The project was carried out in co-operation with project TS19, "Design criteria for slab track structures".

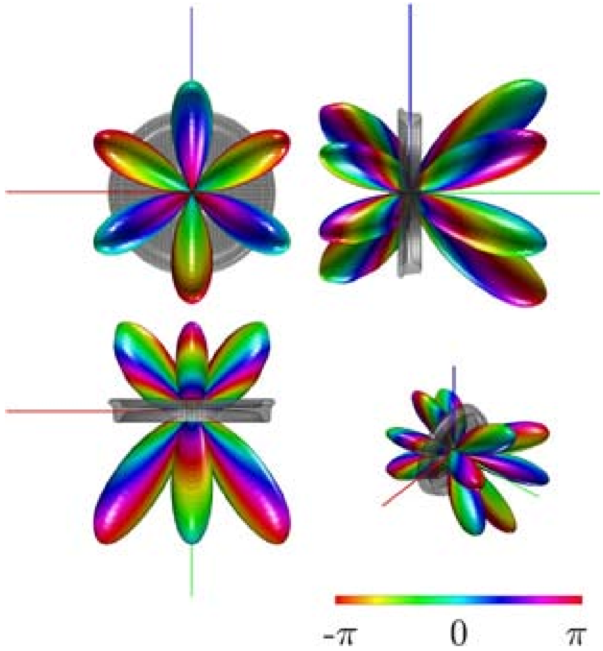
The main components involved in the generation of rolling noise are the wheels, the rails and the sleepers or slab track surface. The wheels and the track are excited by the rolling contact forces resulting from the roughness on the contacting surfaces. In the previous project VB10, a time-domain approach for predicting these forces due to roughness excitation was developed, which served as the starting point for project VB13.

In VB13, high-frequency numerical models for the structural vibration in, and sound radiation from, ballasted and slab tracks were developed. To allow for a wide range of track and wheel geometries, physical models employing Finite Element (FE) and Boundary Element (BE) methods were utilised. A typical challenge when using such methods in combination with large geometries at high frequencies is the computational effort required. This effort has been addressed in several ways in VB13, facilitating the efficient computation of the sound radiation from various tracks. One central element is the convolution of the structural vibration with precalculated acoustic impulse responses to predict the sound radiation. Such impulse responses are used for both the track and wheel radiation.

A time-domain model for predicting the sound pressure radiated by vibrating railway wheels was developed. The mode shapes of the wheel are predicted using an FE approach. For each mode, the radiation pattern is then calculated using an axisymmetric formulation of the BE method. The complexity of the radiation pattern is reduced by employing spherical harmonic equivalent sources.
For each structural mode, given a unit modal amplitude, a spherical harmonics representation of the sound pressure field around the wheel is calculated. This allows for an efficient prediction of the modal pressure impulse responses for various relative positions of the wheel and the receiver. Convolution of each such impulse response (for each mode, and given the relative position of wheel and receiver at each time step) with the time-domain representation of the modal velocity amplitudes predicts the sound pressure at a stationary receiver.

In a similar manner, the radiation from the track is calculated using precalculated impulse responses. These are predicted in the wavenumber-frequency domain using the wavenumber domain BE method, and they describe the pressure signal at a track-side receiver due to a unit velocity on a surface node of the rail. Since the acoustic geometry around the track can be assumed identical even for differ-

VB13. (cont'd)



Left: Vibration pattern of a wheel in an axial mode (eigenfrequency 2120 Hz) with three nodal diameters and one nodal circle. Right: Acoustic directivity of this mode at 1000 Hz

ent track parameters and excitations, these functions can be reused. Multiplication with the rail and sleeper vibration in the wavenumber-frequency domain, and a 2D inverse Fourier transform, leads to the trackside pressure generated by a passing force on the rail. The investigation of the sound generated by slab tracks is realised by discretely coupling two infinite waveguides, the slab and the rail, in one model for both the vibration and radiation. The radiation from the sleeper vibration in a ballasted track is efficiently realised by representing the sleeper vibration in the wavenumber domain.

Practical investigations regarding the noise reduction potential of slab tracks have been carried out. Notably, slab tracks with two-stage elastic supports, such as tracks with booted sleepers, show potential for noise mitigation. By increasing the rail pad stiffness and decreasing the stiffness of the boot, noise radiation from the rail can be reduced without increasing the load on the substructure. This was investigated through simulations in a parametric study. On the wheel side, the presence of the acoustically reflective slab surface, compared to the absorbing ballast surface of ballasted tracks, did not significantly increase the radiation efficiency of the wheel. Important modes for noise radiation from the wheel were identified. It was found that the low-order axial and radial modes, with a strong coupling between vertical and lateral vibration, dominate the equivalent sound pressure level during the pass-by.

Jannik Theyssen successfully defended his doctoral dissertation (see below) on 15 December 2022. The discussion was led by the external examiner, Professor David Thompson (Institute for Sound and Vibration Research, Southampton, UK). Jannik Theyssen has continued his employment at Chalmers and was engaged part-time in project EU21 (In2Track3) during 2023.

Jannik Theyssen, Astrid Pieringer and Wolfgang Kropp: Noise and vibration mitigation on low-vibration track, *Proceedings 21st Nordic Seminar on Railway Technology*, Tampere (Finland) June 2022 (Summary and PowerPoint presentation)

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Jannik Theyssen, Thomas Deppisch, Astrid Pieringer and Wolfgang Kropp: On the efficient simulation of pass-by noise signals from railway wheels, *Journal of Sound and Vibration*, vol 564, 2023, 18 pp, doi.org/10.1016/j.jsv.2023.117889

Jannik Theyssen: Towards time-domain modelling of wheel/rail noise: Effect of the dynamic track model, *IMechE Journal of Rail and Rapid Transit*, vol 238, issue 4, 2024, pp 350–359 doi.org/10.1177/09544097231179514

Jannik Theyssen, Astrid Pieringer and Wolfgang Kropp: Efficient calculation of the three-dimensional sound pressure field around a slab track, *Acta Acustica*, vol 8, 2024, 12 pp doi.org/10.1051/aacus/2023068

Jannik Theyssen, Astrid Pieringer and Wolfgang Kropp: Optimizing components in the rail support system for dynamic vibration absorption and pass-by noise reduction, *Proceedings 14th International Workshop on Railway Noise (IWRN14, online conference)*, Shanghai (P R China) December 2022. In Xiaozhen Sheng, David Thompson, Geert Degrande, Jens Nielsen, Pierre-Etienne Gautier, Kiyoshi Nagakura, Ard Kuijpers, James Tuman Nelson, David Towers, David Anderson and Thorsten Tielkes (editors): Lecture Notes in Mechanical Engineering, *Springer Nature Singapore*, 2024, pp 673–681 doi.org/10.1007/978-981-99-7852-6_64

MU22. IMPROVED CRITERION FOR SURFACE INITIATED RCF

Förbättrat kriterium för ytinitierad rullkontaktutmattning

Project leader	Professor Anders Ekberg, Mechanics and Maritime Sciences / Division of Dynamics
Co-workers	Professor Elena Kabo and Professor Roger Lundén, Mechanics and Maritime Sciences
Doctoral candidate	None (only senior researchers in this project)
Period	2007-07-01 – 2024-06-30 (–2027-06-30)
Chalmers budget (excluding university basic resources)	Stages 5–9: kSEK 3 500 Stage 10: kSEK 400 Stage 11: kSEK 500
Industrial interests in-kind budget	Stages 5–9: kSEK 470 + 600 + 300 Stage 10: kSEK 100 + 50 + 50 Stage 11: kSEK 100 + 50 + 50 *(Alstom + Lucchini + SweMaint)*

From the left: Professor Anders Ekberg, Professor Roger Lundén and Professor Elena Kabo in project MU22

Several CHARMEC projects have been, and are, related to material and structural deterioration. Project MU22 aims to develop and improve analyses and predictive abilities for railway deterioration phenomena, with a focus on rolling contact fatigue (RCF). It also aims to facilitate the operational implementation of derived knowledge and predictive capabilities, providing suggestions for, and reviewing, operational regulations and design/maintenance practices. Examples of applications include operational monitoring and mitigation of (RCF) deterioration, and the inclusion of (RCF) deterioration in LCC and RAMS analyses. Project MU22 also supports other CHARMEC projects dealing with deterioration and provides expertise to projects where material and structural deterioration is of interest but not a core topic. The activity includes interaction with research and industry partners (within and outside CHARMEC) to uphold and develop world-leading competence in the field of material and structural deterioration, with a focus on RCF of railway wheels and rails.

Meetings have been held with our partners to plan, evaluate and disseminate research, including workshops within Trafikverket's Areas of Excellence and seminars arranged by Chalmers Area of Advance Transport. Interaction with international colleagues has included a meeting with Professor Nalinaksh S Vyas, Indian Institute of Technology in Kanpur, and a visit to Lucchini in Lovere, Italy.

The facilitation of implementation has included support in assessing the track load-carrying capacity concerning 6-axle locomotives in collaboration with Trafikverket and Green Cargo, evaluating the consequences of increased axle load on the Iron Ore Line in northern Sweden (STAX 30+), and investigating the (lack of) effect of Under Sleeper Pads (USP) on the main line track of the Iron Ore Line.

Research on track buckling resulted in a framework for quantifying track buckling resistance, described in a journal paper. The framework was further calibrated through an in-depth analysis of operational track buckling events. It was also employed to assess the risk of track buckling on the Iron Ore Line following a derailment. This assessment, which included an analysis of the risk related to induced rail cracks, supported the drafting of a monitoring and maintenance plan by Trafikverket, which allowed traffic to resume.

Since 2019, Anders Ekberg has served as chairman for the International Conference on Contact Mechanics and Wear of Rail/Wheel Systems. A presentation on "Rail and wheel health management" (by Anders Ekberg, Elena Kabo, and Roger Lundén) was delivered at CM2022 in Melbourne. Additionally, a presentation on "Rail and wheel health management" (by Anders Ekberg, Elena Kabo, and Jens Nielsen) was given at the ICRI workshop on "Modelling broken rail and derailment risk" in connection with this conference. Further dissemination activities have included an online presentation by Anders Ekberg on "Track health monitoring and prediction – Possibilities and challenges" at the conference Integrated Computational Materials, Process and Product Engineering (IC-MPPE 2022), organised by Montanuniversität Leoben; a presentation on "Squats – Numerical prediction of initiation and growth" at an international research seminar on squats organised online on 23 May 2022 by TU Delft; and a course on railway mechanics with a focus on wheel deterioration with Lucchini Sweden in Surahammar on 1 June 2023.

Implementation of research results in teaching is one of the dissemination activities in project MU22. Anders Ekberg and Elena Kabo, together with Jens Nielsen and

MU22. (cont'd)

Material roll-out and detachment in a switch rail on the Iron Ore Line

Björn Pålsson, have developed and taught the new course "Railway Technology" (MMS 180) for students in the new Master's Programme Mobility Engineering at Chalmers. The course features lectures, tutorials, assignments, and two study visits in co-operation with Alstom and SYSTRA. Elena Kabo and Anders Ekberg also developed and taught the course "Project in Railway Technology" (MMS 200) within the same programme. Here, students gain knowledge in project management applied to industry-initiated and guided projects. The course includes a study visit to SweMaint's maintenance workshop. Anders Ekberg and Elena Kabo also supervised a MSc thesis on the influence of material defects on subsurface-induced rolling contact fatigue by Jaseung Lee, and a BSc thesis by Eric Thorén and Gabriel Hasl, see below.

Anders Ekberg was a member of the grading committee for Rayendra Anandika, who defended his dissertation "Non-destructive measurement of near-surface cracks in railheads with focus on ultrasonic inspections" on 17 November 2021 at Luleå University of Technology. Anders Ekberg was deputy member of the grading committee when Xiao Lang at M2, Division of Marine Technology, defended his doctoral dissertation "Data-driven ship performance models – Emphasis on energy efficiency and fatigue safety" on 23 February 2023. On 20 December 2024, Anders Ekberg was the faculty-appointed examiner at the public defence by Mahdi Khosravi, Operation and Maintenance Engineering, LTU, of the doctoral dissertation "Leveraging data-driven and alignment techniques for optimal railway track maintenance scheduling". For the joint reference group, see under project TS20.

Nicola Zani, Magnus Ekh, Anders Ekberg and Angelo Mazzù: Application of a semianalytical strain assessment and multiaxial fatigue analysis to compare rolling contact fatigue in twin-disk and full-scale wheel/rail contact conditions, *Fatigue & Fracture of Engineering Materials & Structures*, vol 45, issue 1, 2022, pp 222–238, doi.org/10.1111/ffe.13595

Danial Molavitabrizi, Anders Ekberg and Mahmoud Mousavi: Computational model for low cycle fatigue analysis of lattice materials – Incorporating theory of critical distance with elastoplastic homogenization, *European Journal of Mechanics – A/Solids*, vol 92, 2022, 13 pp doi.org/10.1016/j.euromechsol.2021.104480

Knut Andreas Meyer, Daniel Gren, Johan Ahlström and Anders Ekberg: A method for in-field railhead crack detection using digital image correlation, *International Journal of Rail Transportation*, vol 10, issue 6, 2022, pp 675–694 (also listed under projects MU30 and MU35), doi.org/10.1080/23248378.2021.2021455

Jaseung Lee: Influence of small wheel defects on the risk of subsurface-initiated rolling contact fatigue of railway wheels, MSc Thesis, *Chalmers Mechanics and Maritime Sciences*, Gothenburg 2023, 42 pp odr.chalmers.se/items/fdb1b935-52b6-4f01-8d7e-d5bd17391d35

Erika Steyn, Björn Paulsson, Anders Ekberg and Elena Kabo: Rail machining – Current practices and potential for optimization, *IMechE Journal of Rail and Rapid Transit*, vol 238, issue 2, 2023, pp 196–205 (also listed under projects MU36 and EU21) doi.org/10.1177/09544097231187978

Anders Ekberg, Elena Kabo and Roger Lundén: Rail and wheel health management, *Wear*, vol 526–527, 2023, 10 pp (revised article from conference *CM2022*. Also listed under project SP32) doi.org/10.1016/j.wear.2023.204891

Anders Ekberg and Elena Kabo: Asset management – A brief introduction with focus on the ISO 55000 standard and mechanical deterioration of railway related assets, Research Report 2022:04, *Chalmers Mechanics and Maritime Science*s, Gothenburg 2024, 21 pp (also listed under project SP 32)

Anders Ekberg: Railway propulsion – A brief introduction, Research Report 2024:05, *Chalmers Mechanics and Maritime Sciences*, Gothenburg 2024, 28 pp

Elena Kabo and Anders Ekberg: Characterisation of track buckling resistance, *IMechE Journal of Rail and Rapid Transit*, vol 238, issue 7, 2024, pp 786–794 (also listed under project EU21) doi.org/10.1177/09544097241231884

Anders Ekberg: Ibruktagande efter urspårning – Malmbanan (Commissioning after derailment – The Iron Ore Line, in Swedish), *Chalmers Mechanics and Maritime Sciences*, Gothenburg 2024, 19 pp

Eric Thorén and Gabriel Hasl: Kostnadsanalys av spårväxlar hos Trafikverket – En analys av en uppgradering med målet att uppnå kostnadsbesparingar (Cost analysis of track switches at the Swedish Transport Administration – An analysis of an upgrade with the aim of achieving cost savings, in Swedish), BSc Thesis, *Chalmers Mechanics and Maritime Sciences*, 2024, 41 pp hdl.handle.net/20.500.12380/308052

Anders Ekberg and Elena Kabo: Estimating residual risks for rail breaks, *Proceedings 22nd Nordic Seminar on Railway Technology*, Stockholm (Sweden) June 2024 (Summary and PowerPoint presentation)

MU30. MODELLING OF PROPERTIES AND DAMAGE IN WHEEL AND RAIL MATERIALS

Modellering av egenskaper och skador i hjul- och rälmaterial

Project leader	Professor Johan Ahlström, Industrial and Materials Science / Division of Engineering Materials
Doctoral candidate	None (only senior researcher in this project)
Period	2013-04-18 – 2024-06-30 (– 2027-06-30)
Chalmers budget (excluding university basic resources)	Stage 7: kSEK 1 290 Stage 8: kSEK 1 275 (+ 229 in S2R) Stage 9: kSEK 450 (+ 1 682 in S2R) Stage 10: kSEK 850 (+ 1 823 in S2R and ER) Stage 11: kSEK 1200 (+ 1 700 in ER)
Industrial interests in-kind budget	Stage 7: kSEK 50 + 50 + 15 + 50 + 200 Stage 8: kSEK 50 + 50 + 15 + 0 + 200 Stage 9: kSEK 50 + 50 + 15 + 0 + 150 Stage 10: kSEK 50 + 50 + 30+ 0 + 150 Stage 11: kSEK 50 + 50 + 20+ 0 + 150 *(Alstom + Lucchini + SYSTRA + Trafikverket + voestalpine)*

The main objective of this senior research project is to contribute to the synthesis and interpretation of results from previous and ongoing experimental projects, and to guide their implementation into material models of sufficient complexity to capture important phenomena. Accurate, yet efficient, material models are crucial for the simulation of material deformation, as well as crack initiation and growth. The integration between the two research areas of materials science and applied mechanics has been fruitful. Collaboration with external parties in the field of materials science is another objective that promotes quality and increases dissemination.

In collaboration with colleagues at the Technical University of Denmark (DTU) and the European Synchrotron Radiation Facility (ESRF), further experiments using dark field X-ray microscopy (DFXM) have been conducted to study the wheel material ER7T, which had previously been subjected to low-cycle fatigue loading (cyclic plasticity). The main research question was to investigate the stability of residual stresses at the local level, such as in individual free ferrite grains, which is crucial for accurate modelling of stress relaxation. The results show that heat treatment at temperatures ranging from 300 to 600 °C induces an increasing amount of stress relaxation, although the results around 500 °C were surprising. Further studies, including in-situ heat treatments, are planned in collaboration with the principal investigator at ESRF, Dr Can Yíldírím, and his post-doctoral researchers, funded by a long-term ERC grant. The results of previous synchrotron studies were presented at the 11th International Conference on Residual Stresses held in Nancy, France, in March 2022, and at the 42nd Risø International Symposium on Materials Science in Denmark in September 2022, see below.

Photo taken after the successful doctoral defence at TU Vienna, in front of the Neptune statue at Albertinaplatz. From left to right: the examiner Professor Paul Mayrhofer, Dr Matthias Freisinger, Dr Klaus Six, and Professor Johan Ahlström

During Stage 10, collaboration between MU30 and the doctoral students Eric Voortman Landström in SD11 and Erika Steyn in project MU36 has resulted in an improved prediction of the stresses arising in railway wheels during and after block braking, and how the material properties are affected by such cycles. This is important for assessing safe continued operation. A similar collaboration with Björn Andersson in project MU37 contributed to predicting residual stresses and strength variations following repair welding of rails. Additionally, a study together with Knut Andreas Meyer at Technishe Universität Braunschweig was completed, based on experiments carried out in project MU34.

Much of the work was related to EU projects, and our international network provided opportunities for networking, learning, and quality assurance. For example, in October 2023 Johan Ahlström was invited as the external reviewer for a doctoral dissertation at Vienna University of Technology (TU Vienna), where Matthias Freisinger defended his thesis "On the formation of stratified surface layers associated to fatigue cracks on rail wheels", supervised by Paul Mayrhofer from TU Vienna and Klaus Six and Gerald Trummer from Virtual Vehicle in Graz. In line with our previous studies, Matthias Freisinger used laser irradiation to simulate the frictional heating damage occurring on railway wheel surfaces and assessed the impact on subsequent Rolling Contact Fatigue (RCF) loading. An application for funding to continue the studies will be submitted to the Austrian Science Fund (FWF), with a link to CHARMEC.

For the joint reference group, see under project TS20.

MU30. (cont'd)

Can Yildirim, Yubin Zhang, Erika Steyn, Fang Liu, Carsten Detlefs and Johan Ahlström: Exploring three-dimensional orientation and residual stresses in railway steels, *Proceedings 11th International Conference on Residual Stresses (ICRS 11)*, Nancy (France) March 2022 (Summary and PowerPoint presentation)

Yubin Zhang, Casey Jessop, Dimitrios Nikas, Tianbo Yu, Wenjun Liu and Johan Ahlström: Stress relief during annealing of railway wheel steel characterized by synchrotron X-ray micro-diffraction, *Proceedings 42nd Risø International Symposium on Materials Science*, Risø/Roskilde (Denmark) September 2022, IOP Conference Series: Materials Science and Engineering, vol 1249, 6 pp, doi.org/10.1088/1757-899X/1249/1/012043

Dimitrios Nikas, Yubin Zhang and Johan Ahlström: Effect of annealing on microstructure in railway wheel steel, *ibidem*, 6 pp doi.org/10.1088/1757-899X/1249/1/012059

Knut Andreas Meyer, Daniel Gren, Johan Ahlström and Anders Ekberg: A method for in-field railhead crack detection using digital image correlation, *International Journal of Rail Transportation*, vol 10, issue 6, 2022, pp 675-694 (also listed under projects MU37 and MU39), doi.org/10.1080/23248378.2021.2021455

Björn Andersson, Johan Ahlström, Magnus Ekh and Lennart Josefson: Homogenization based macroscopic model of phase transformations and cyclic plasticity in pearlitic steel, *Journal of Thermal Stresses*, vol 45, issue 6, 2022, pp 470-492 (also listed under projects MU37 and MU39) https://doi.org/10.1080/01495739.2022.2056557

Eric Voortman Landström, Erika Steyn, Johan Ahlström and Tore Vernersson: Thermomechanical testing and modelling of railway wheel steel, *International Journal of Fatigue,* vol 168, 2023, 11 pp (also listed under projects MU36 and SD11) doi.org/10.1016/j.ijfatigue.2022.107373

Knut Andreas Meyer and Johan Ahlström: The role of accumulated plasticity on yield surface evolution in pearlitic steel, *Mechanics of Materials*, vol 179, 2023, 11 pp doi.org/10.1016/j.mechmat.2023.104582

Daniel Gren and Johan Ahlström: Fatigue crack propagation on uniaxial loading of biaxially predeformed pearlitic rail steel, *Metals*, vol 13, no 10, 2023, 18 pp (also listed under project MU35) https://doi.org/10.3390/met13101726

Daniel Gren, Johan Ahlström and Magnus Ekh: Fatigue crack characteristics in gradient predeformed pearlitic steel under multiaxial loading, *Advanced Engineering Materials*, vol 26, issue 19, 2024, 13 pp (also listed under projects MU35 and MU39) doi.org/10.1002/adem.202400950

Erika Steyn and Johan Ahlström: Thermo-mechanical response of near-pearlitic steel heated under restriction of thermal expansion, *Journal of Materials Research and Technology*, vol 32, 2024, pp 1714-1724 (also listed under project MU36) doi.org/10.1016/j.jmrt.2024.07.107

Nasrin Talebi, Johan Ahlström, Magnus Ekh and Knut Andreas Meyer: Evaluations and enhancements of fatigue crack initiation criteria for steels subjected to large shear deformations, *International Journal of Fatigue*, vol 182, 2024, 12 pp (also listed under project MU41), doi.org/10.1016/j.ijfatigue.2024.108227

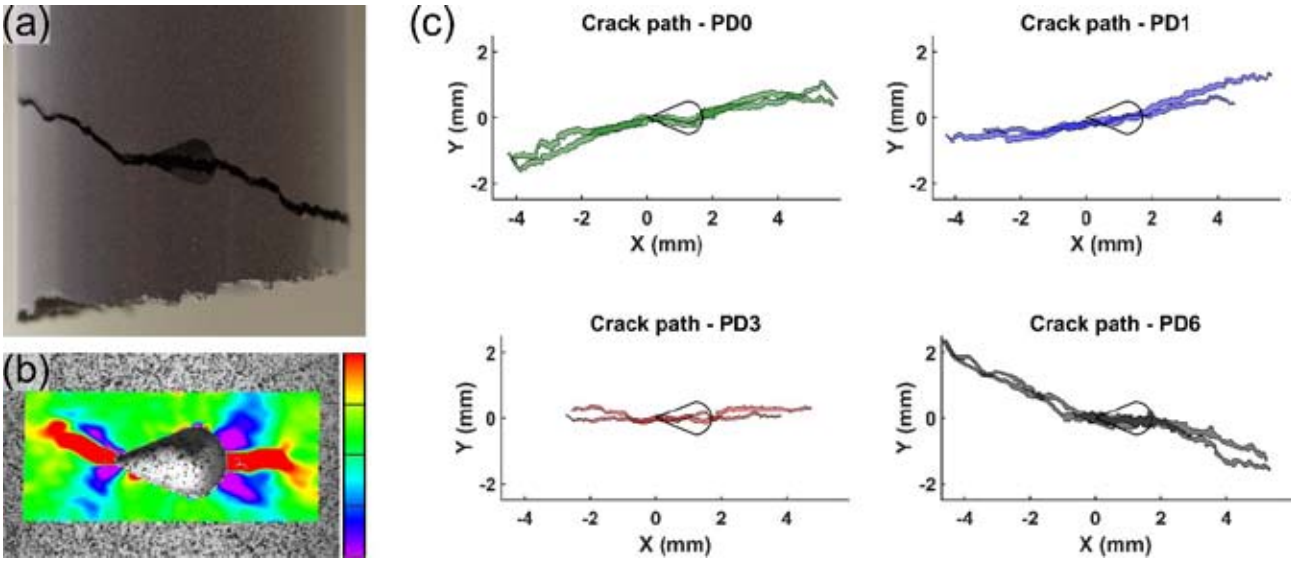
MU35. CHARACTERIZATION OF CRACK INITIATION AND PROPAGATION IN ANISOTROPIC MATERIAL

Karakterisering av sprickinitiering och propagering i anisotropt material

Project leader and supervisor	Professor Johan Ahlström, Industrial and Materials Science / Division of Engineering Materials
Assistant supervisor	Professor Magnus Ekh, Industrial and Materials Science
Doctoral candidate	Mr Daniel Gren (from 2019-06-10; Lic Eng Aug 2022; PhD June 2024)
Period	2019-06-10 – 2024-06-30
Chalmers budget (excluding university basic resources)	Stage 9: kSEK 1 000 (+ 1 237 in S2R) Stage 10: kSEK 2 168 + 450 (+ 1 743 in S2R and ER)
Industrial interests in-kind budget	Stage 9: kSEK 0 + 0 + 200 Stage 10: kSEK 50 + 30 + 200 *(Alstom + Green Cargo + voestalpine)*

The material properties near the contact surfaces of pearlitic railway rails and wheels are not finalised during the manufacturing process but develop in service through rolling contact loading. The cumulative cold deformation that occurs leads to work hardening, which increases the strength of the material and produces compressive residual stress in the surface layer. However, it also results in an alignment of the microstructure and subsequent anisotropic material properties. In fact, the microstructure that develops close to the rail surface is similar to that of drawn pearlitic steel wires, which are among the highest strength materials used for engineering purposes, with tensile strengths exceeding 6 GPa. This unrivalled strength is believed to be due to the anisotropic, aligned microstructure, which diverts microcracks to directions parallel to the loading direction. However, in the railhead, the alignment caused by the contact stresses is not evenly distributed and decreases with increasing depth below the surface. Although the hardening and microstructural alignment at the very surface may be beneficial, there is a risk that the anisotropic properties can guide cracks to propagate down into the rail or wheel.

MU35. (cont'd)



In (a), the notched test bar and the crack pattern post-failure are shown for the highest pre-strain level PD6. In (b), DIC is used to visualise the localisation of the axial surface strain around the notch. In (c), the crack path for different levels of pre-strain is plotted as a function of the projected distance from the sharp end of the notch (X). A significant effect of pre-strain level is observed, changing the crack path going from undeformed (PD0), which is fully controlled by the stress state, to gradually increasing levels of pre-strain (PD1, PD3 and PD6), resulting in a crack path increasingly aligned with the aligned microstructure

Understanding anisotropic strength, toughness, and fatigue properties is necessary for effective mitigation of rolling contact fatigue (RCF), resulting in longer life and lower life cycle costs, and for building and calibrating models useful for accurate prediction.

The aim of project MU35 was to better understand the anisotropy that develops in wheel and rail surfaces during service and its effect on properties and fatigue crack behaviour. Both mechanical properties and fracture characteristics change dramatically as anisotropy increases. The PhD student Daniel Gren used a method, developed and evaluated in the previous CHARMEC projects MU28 and MU34, to pre-deform R260 rail specimens, ensuring that the material properties mirror those found in field samples. Fatigue crack initiation and propagation experiments were then conducted on this anisotropic material to study fatigue crack initiation and growth, as well as crack paths under different loading modes. These studies provide a more robust foundation for modelling work and enhance the accuracy of predicting safety limits and maintenance actions.

Methodologies have been developed for fatigue crack initiation and propagation experiments under uniaxial, pulsating torsional, and non-proportional multiaxial loading. The methodology includes predeformation, shear strain measurement, notch fabrication, development of control programs for mechanical testing and crack measurement using optical (OM), stereo (SOM), and scanning electron microscopes (SEM), and digital image correlation (DIC). Scripts have also been developed to calculate the true crack length (curvature correction is considered), including edge detection and data analysis. The studies generally demonstrated good repeatability between identical tests and well-defined crack growth rates. A general challenge is that the influence of anisotropy is difficult to isolate from the influence of work hardening, a fact which should be addressed in future work.

Microscopy of cracks and characterisation of anisotropy were carried out throughout the project, both on samples from the field and on those produced in the laboratory. In a study for Trafikverket, pearlitic rail field samples with varying degrees of rail head damage were examined using metallographic techniques. The crack positions, lengths, depths, and angles were recorded. A weak correlation was found between crack surface length and crack depth, but this was not considered sufficient for maintenance planning. Therefore, a further study was conducted in collaboration with project MU34, which concluded that the rail head displacement field under rail bending, induced by the weight of the measurement train, can be used to detect surface cracks with a correlation to crack depth. This could enhance rail condition monitoring in the field.

The uniaxial and torsional fatigue crack propagation experiments showed that fatigue life is dependent on the material state, with predeformed material exhibiting a longer fatigue life than virgin material. The effect of predeformation on the direction of crack growth was limited

MU35. (cont'd)

From the left: Johan Ahlström, Magnus Ekh, Anton Hohenwarter, Svjetlana Stekovic (Linköping University), Daniel Gren, Erik Olsson (Luleå University), Jens Bergström (Karlstad University) and Christer Persson (Chalmers) after the doctoral examination in project MU35 on 14 June 2024

under uniaxial loading but was dependent on the material state under torsional loading. In the multiaxial fatigue crack propagation experiments, the direction of crack growth was significantly influenced by predeformation. The higher the degree of predeformation, the more the crack tended to follow the aligned microstructure, indicating strong anisotropy in fatigue crack propagation, see figure. In addition to these experiments, fatigue crack propagation was studied in situ using a test rig in a SEM. Single edge notched specimens machined from predeformed test bars were examined. One observation was that more deformed material behaved more brittle during the final fracture. This was a first attempt to locally characterise the effect of microstructure alignment on crack growth and crack paths.

Daniel Gren presented his licentiate thesis (see below) at a seminar on 30 August 2022, where Professor Jens Bergström from Karlstad University introduced the discussion. Additionally, Daniel Gren successfully defended his doctoral dissertation (see below) on 14 June 2024, with Dr Anton Hohenwarter from the University of Leoben, Austria, as the faculty-appointed external examiner.

Daniel Gren continues his employment and is engaged part-time in CHARMEC. For the joint reference group, see under project TS20.

Daniel Gren: Effect of large shear deformation on fatigue crack behavior in pearlitic rail steel, Licentiate Thesis, *Chalmers Industrial and Materials Science*, Gothenburg August 2022, 90 pp (Summary and two appended papers) research.chalmers.se/en/publication/531677

Knut Andreas Meyer, Daniel Gren, Johan Ahlström and Anders Ekberg: A method for in-field railhead crack detection using digital image correlation, *International Journal of Rail Transportation*, vol 10, issue 6, 2022, pp 675-694 (also listed under projects MU22 and MU30), doi.org/10.1080/23248378.2021.2021455

Daniel Gren and Johan Ahlström: Fatigue crack propagation on uniaxial loading of biaxially predeformed pearlitic rail steel, *Metals*, vol 13, no 10, 2023, 18 pp (also listed under project MU30) https://doi.org/10.3390/met13101726

Daniel Gren and Knut Andreas Meyer: Effects of predeformation on torsional fatigue in R260 rail steel, *International Journal of Fatigue*, vol 179, 2024, 10 pp, doi.org/10.1016/j.ijfatigue.2023.108031

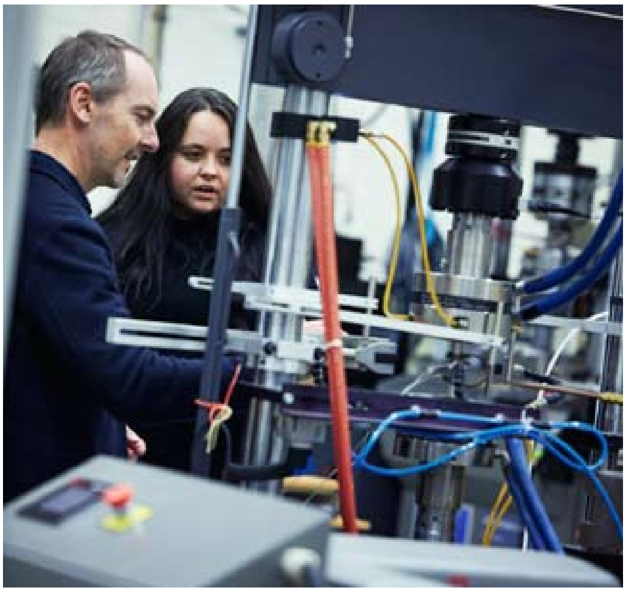
Daniel Gren, Johan Ahlström and Magnus Ekh: Fatigue crack characteristics in gradient predeformed pearlitic steel under multiaxial loading, *Advanced Engineering Materials*, vol 26, issue 19, 2024, 13 pp (also listed under projects MU30 and MU39) doi.org/10.1002/adem.202400950

Daniel Gren: Fatigue crack behaviour in pearlitic railway rails subjected to large shear deformation, Doctoral Dissertation, *Chalmers Industrial and Materials Science*, Gothenburg June 2024, 160 pp (Summary and 5 appended papers) research.chalmers.se/en/publication/541325

MU36. MATERIAL CHARACTERISTICS IN WELDING AND OTHER LOCAL HEATING EVENTS

Materialkarakteristik vid svetsning och annan lokal upphettning

Project leader and supervisor	Professor Johan Ahlström, Industrial and Materials Science / Division of Engineering Materials
Assistant supervisor	Professor Magnus Ekh, Industrial and Materials Science
Doctoral candidat	Ms Erika Steyn (from 2019-06-10; Lic Eng Oct 2022; PhD June 2024)
Period	2019-06-10 – 2024-06-30
Chalmers budget (excluding university basic resources)	Stage 9: KSEK 1 000 (+ 1 073 in S2R) Stage 10: KSEK 1 870 + 450 (+ 1 815 in S2R and ER)
Industrial interests in-kind budget	Stage 9: KSEK 0 + 0 + 0 +200 Stage 10: KSEK 100 + 30 + 100 + 100 *(Alstom + Green Cargo + Lucchini + voestalpine)*



Erika and Johan working on the advanced thermo-mechanical fatigue test rig, where the test preparations are rigorous. The thermo-mechanical fatigue tests apply loadings to wheel and rail specimens that are representative of those experienced by a block-braked wheel or a rail during welding, i e the simultaneous application of varying temperature and varying mechanical strain. The simulations in SD11 applied these results to enhance the prediction of stresses and distortions in block-braked wheels

The significant impact of heat treatment on steel microstructure and properties offers the possibility of tailoring the steel properties and even introducing beneficial gradients in properties and residual stresses. However, while this is advantageous in the production of steel products, it may be detrimental if heat treatment occurs during product use.

Welding and grinding processes cause short-term local heating of the material. Short-term local frictional heating in railway operations can also occur when the wheelset of a railway vehicle slips along the rail, for example, due to malfunctioning braking or traction systems, or climatic conditions. The resulting local temperature rise leads to loss of beneficial residual stresses, material degradation, and phase transformations, which can be followed by cracking in the rail and wheel surfaces during subsequent rolling contact loading. There are many parallels between the behaviour of the base material during welding and the thermal damage caused by frictional heating, and both areas benefit from a combined study. The result of local heating, whether induced by welding or friction, is a degraded or altered structure, with a gradient in mechanical properties and residual stresses. As with all new technologies that are to be developed and successfully implemented in the field following rigorous safety assessments, a sound scientific basis is required.

Project MU36 focused on material behaviour under combined thermal and mechanical loading, particularly thermo-mechanical fatigue (TMF) properties. This experimentally oriented project continued from the work in Stage 9 with the simulation of block braking and other large heat input processes. Specifically, cyclic thermal loading with restricted thermal expansion was imposed to support model development for block braking simulation in project SD11. The thermal expansion was limited to 0, 25, 50, 75 and 100% in the tests, resulting in different amounts of plastic and viscoplastic strain. The studied temperature cycles mimic the heating experienced by the material in wheels during severe, long-term block braking (up to 45 minutes). The different peak temperatures 300, 400, 600 and 650 °C represent expected worst-case scenarios in the wheel web and wheel rim, respectively. It was found that the higher temperatures associated with overheating of the rim material could be very detrimental to the residual stress state of the wheel, changing from the compressive stress level after production and running-in to a tensile stress level after severe block braking. This could promote fatigue crack propagation in service. The microstructure of the material was also altered in the more severe tests, reducing the strength by up to 20%.

Several types of experiments were carried out to investigate shorter heating cycles, typical of slip and repair welding scenarios. The experiments were complemented by process simulations carried out in project MU37. The innovative use of two types of equipment to simulate frictional heating in the laboratory was evaluated, both of them using a laser beam as the heat source. A standard laser welding machine and an additive manufacturing equipment were

MU36. (cont'd)

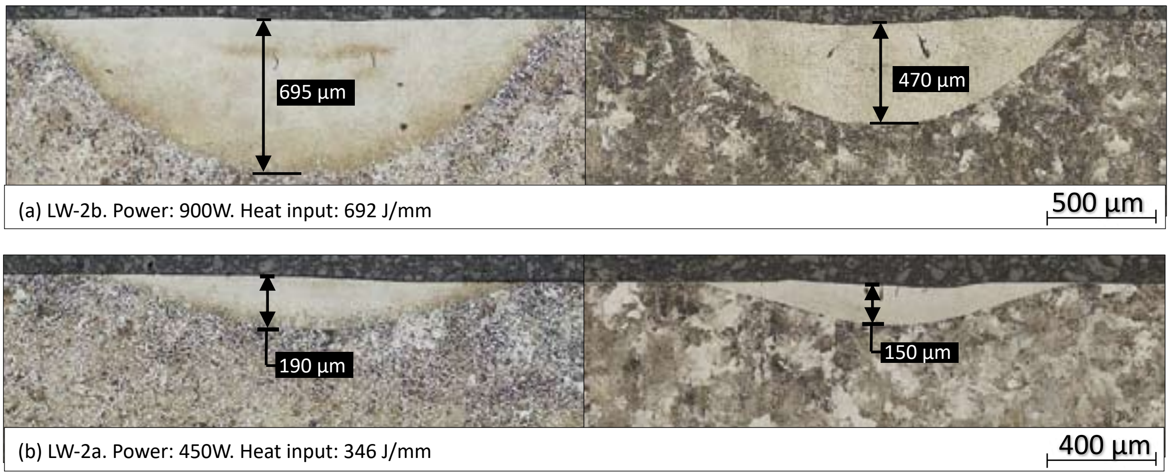
Lasers have been used in previous CHARMEC projects to successfully simulate short-term frictional heating damage to wheels and rails. The image shows a sample extracted from a rail head, alongside a fixture for mounting it in an additive manufacturing machine. This innovative application of controlled laser power successfully replicated short-term frictional heating with extreme lateral resolution

used without any filler material, allowing the laser beam to hit the surfaces of the rail (R260) and wheel (R7T) materials, respectively. This allowed the heating to be controlled in terms of power and duration and proved valuable for assessing the material transformations that occurred. The figure illustrates the microstructure in cross-sections after welding passes, resulting in a martensitic transformation in a lenticular volume below the heat source. Additionally, the austenitic manganese steel used in crossing noses has been studied via laser heating as part of a master's thesis associated with MU36 and the In2Track3 project.

The residual stress after the laser beam passes showed significant differences between the two materials, with the higher carbon steel R260 exhibiting more compressive stress due to the shift in martensite formation temperature during cooling. This observation provides important information for materials selection, highlighting the risk of martensitic transformation during the maintenance and operation of wheels and rails.

To investigate frictional heating in another context, a study of rail grinding was carried out in collaboration with a master's thesis. Rail steel samples R260 and R350HT were ground with different parameter settings using an industrial grinding machine adapted to simulate rail grinding.
A special grinding stone, similar to the one used in rail grinding, was employed, and the experiments were carried out in dry conditions (without lubrication). A high feed rate resulted in much thinner martensite layers, while the depth of cut had little effect. The similarity in martensitic microstructures and mechanical behaviour between the frictional heating in the grinding experiment and the laser heating experiments carried out in the other studies demonstrates that laser heating in a laboratory environment may well represent frictional heating in the field.

Erika Steyn presented her licentiate thesis (see below) at a seminar on 28 October 2022, where Professor Johan Moverare from Linköping University introduced the discussion. Additionally, Erika Steyn successfully defended her doctoral dissertation (see below) on 5 June 2024, with Dr Klaus Six from Virtual Vehicle in Graz, Austria, as the faculty-appointed external examiner. For the joint reference group, see under project TS20.



The microstructure after irradiation of the top surface with a laser welding run of 900 W (top row) and 450 W (bottom row) at a welding speed of 1.3 mm/s. The images in the left column show the R7T wheel steel, while the right column shows the fully pearlitic R260 rail steel. The smaller transformed area at lower power is expected, and the effect of the free ferrite in the R7T wheel material provides a gradual transition from the base material to the martensitic microstructure

MU36. (cont'd)

Erika Steyn and Johan Ahlström: Simulation of repair welding on pearlitic railway steel using additive manufacturing equipment, *Proceedings of the 12th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems* (*CM2022*), Melbourne (Australia) September 2022, pp 639–645

Erika Steyn: Railway wheel steel behaviour upon thermo-mechanical loadings. Licentiate Thesis, *Chalmers Industrial and Materials Science*, Gothenburg October 2022, 93 pp (Summary and three appended papers)
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Eric Voortman Landström, Erika Steyn, Johan Ahlström and Tore Vernersson: Thermomechanical testing and modelling of railway wheel steel, *International Journal of Fatigue*, vol 168, 2023, 11 pp (also listed under projects MU30 and SD11)
doi.org/10.1016/j.ijfatigue.2022.107373

Erika Steyn, Björn Paulsson, Anders Ekberg and Elena Kabo: Rail machining – Current practices and potential for optimisation. *IMechE Journal of Rail and Rapid Transit*, 2023, 10 pp (also listed under projects MU22 and EU21)
doi.org/10.1177/09544097231187978

Caroline Andersson: Formation and characteristics of white etching layers on austenitic steels - An experimental study and evaluation of hardness distribution and changes in the microstructure for austenitic manganese steel with associated comparison of pearlitic steel, MSc Thesis, *Chalmers Industrial and Materials Science*, 2023, 125 pp, hdl.handle.net/20.500.12380/307256

Erika Steyn and Johan Ahlström: Thermo-mechanical response of near-pearlitic steel heated under restriction of thermal expansion, *Journal of Materials Research and Technology,* vol 32, 2024, pp 1714-1724 (also listed under project MU30)
doi.org/10.1016/j.jmrt.2024.07.107

Erika Steyn: Thermo-mechanical behaviour of pearlitic railway steels, Doctoral Dissertation, *Chalmers Industrial and Materials Science*, Gothenburg June 2024, 182 pp (Summary and 6 appended papers), research.chalmers.se/en/publication/541125

Maria Börjesson and Per Emanuelsson: Rail grinding study – Laboratory experiments, metallography and modelling, MSc Thesis, *Chalmers Industrial and Materials Science*, 2024, 61 pp
hdl.handle.net/20.500.12380/308896

Extreme freight transport is achieved by iron ore wagons going from Kiruna to Luleå in Sweden and Narvik in Norway. Wagons, with an empty weight of 20 tonnes and a loaded weight of 120 tonnes, are supported by two bogies and eight wheels. The load 15 tonnes per wheel means a nominal elliptic wheel–rail contact area of 12 by 17 mm and a maximum contact pressure of 1400 MPa, excluding dynamic contributions

MU37. NUMERICAL SIMULATIONS OF WELDING AND OTHER HIGH-TEMPERATURE PROCESSES

Numerisk simulering av svetsning och andra högtemperaturprocesser

Project leader and supervisor	Professor Magnus Ekh, Industrial and Materials Science / Division of Material and Computational Mechanics
Assistant supervisors	Professor Johan Ahlström and Professor Lennart Josefson, Industrial and Materials Science
Doctoral candidate	Mr Björn Andersson (from 2019-03-18; Lic Eng Dec 2021; PhD March 2024)
Period	2019-03-18 – 2024-03-17
Chalmers budget (excluding university basic resources)	Stage 9: kSEK 1 000 (+ 1 116 in S2R) Stage 10: kSEK 1 102 (+ 2031 in S2R and ER)
Industrial interests in-kind budget	Stage 9: kSEK 0 + 0 + 200 Stage 10: kSEK 50 + 30 + 200 *(Alstom + Green Cargo + voestalpine)*

Rail and wheel steels are subjected to very high stresses and, in some cases, also to elevated temperatures. The rolling contact loading results in a multiaxial stress state, combining compression and shear. If the temperature in the steel is increased sufficiently and is followed by rapid cooling, austenite and martensite may develop, which can be detrimental to the steel's properties. Previous research within CHARMEC has focused on models for these phase transformations. However, there was a need to further develop models with a coupling between the phase transformations and the temperature-dependent cyclic mechanical behaviour of the phases in the material. The purpose of project MU37 was to improve the accuracy of simulations of residual stresses after phase transformations and to clarify how the stresses are affected by repeated mechanical contact loading and repeated elevated temperatures. The developed models have been used to address applications such as short heating events (e g, braking situations) and rail welding.

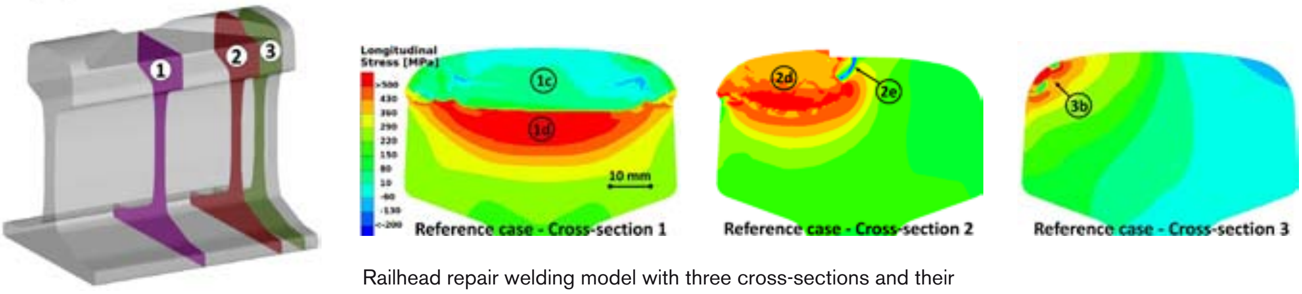
A material model that combines cyclic plasticity and phase transformations was formulated. It has been implemented in Finite Element (FE) simulations of a double wheel flat, involving two heat pulses on the tread of a railway wheel, followed by thirteen over-rollings. The FE analyses showed that high residual tensile stresses were generated below the transformed martensite layer. Depending on the number and duration of the heating events, tensile residual stresses were generated either in the base material or in the tempered martensite layer. These stresses stabilised during the last ten over-rollings after the second cooling, but at very high values. This indicates a risk for crack initiation and propagation, which has also been observed in micrographs of a double wheel flat.

The material model was extended by using different homogenisation methods, and also by considering Transformation Induced Plasticity (TRIP). The resulting models were evaluated against experimental results for a laser heating experiment carried out in project MU29.

An FE simulation methodology for railway repair welding was developed. The material model was extended to include recovery to a virgin material state after cyclic melting and solidification. The simulation methodology was developed by balancing computational efficiency, accuracy and

Doctor Björn Andersson with faculty-appointed external examiner (Håkan Hallberg, fourth from the left) grading committee (Samuel Lorin, Andreas Lundbäck, Kamellia Dalaei, and Zuheir Barsoum), and supervisors (Johan Ahlström, Magnus Ekh, and Lennart Josefson)

MU37. (cont'd)



Railhead repair welding model with three cross-sections and their resulting residual longitudinal stress after the welding procedure

engineering applicability. The results from the simulations, in terms of residual stresses, were validated by comparing them with results from repair welding experiments from literature, as well as from experimental methods exploited in MU37. These methods have been based on using additive manufacturing equipment (3D-printer for powder bed fusion – laser beam) and laser welding equipment.

A simulation-based parameter study of the rail head repair welding process was conducted to investigate the effect of variations in preheating, operating temperatures, and repair geometry on the residual stress state and the resulting material phases. To tune the heat source model in the welding simulations, a railhead welding experiment was conducted in co-operation with Trafikverket's school for rail welders in Ängelholm. The parameter study revealed that the powerful final weld passes with a high heat input contribute significantly to the robustness of the process, making it less sensitive to variations in additional heating procedures. Consistent with field observations, the simulations identified the fusion zone of the base and filler materials, at the start and end stretches of the repaired rail section, as the critical regions in terms of unfavourable material phases and high tensile residual stresses. The studied rail repair weld was then subjected to train wheel over-rollings, and the risk of fatigue crack initiation was evaluated. The study demonstrated that residual tensile stresses at the rail surface from welding are redistributed and relieved by over-rollings, while residual stresses some distance below the rail surface at the fusion zone of the base and filler materials are less affected and remain high.

The project MU37 has been presented and discussed during several biannual workshops with participants from the University of Leoben, voestalpine, and CHARMEC.

Björn Andersson presented his licentiate thesis (see below) at a seminar on 20 December 2021, where Professor Lars-Erik Lindgren from Luleå Technical University introduced the discussion. Additionally, Björn Andersson successfully defended his doctoral dissertation (see below) on 26 March 2024. The faculty-appointed external examiner was Associate Professor Håkan Hallberg from Lund University. Björn Andersson continues his employment at Chalmers as postdoctoral researcher until 1 April 2026. During 2024, he has continued his work in the Europe's Rail project IAM4RAIL (CHARMEC project EU23). For the joint reference group, see under project TS20.

Results from the project have been presented at: Svetskommissionens forskningsdag 2022, Svetskommissionens arbetsgrupp AG60 rälssvetsning, International Conference on Material Modelling in Lund 2019, International Conference on Residual Stresses no XI in Nancy (France) 2022, International Conference on Thermal Stresses in Luleå 2023, International Conference on Simulation for Additive Manufacturing in Munich (Germany) 2023, Nordic Seminar on Railway Technology in Stockholm 2024, and Svenska Mekanikdagar in Gothenburg 2024.

Björn Andersson: Modeling of phase transformations and cyclic plasticity in pearlitic steels, Licentiate Thesis, *Chalmers Industrial and Materials Science*, Gothenburg December 2021, 57 pp (Summary and two appended papers), research.chalmers.se/en/publication/527312

Björn Andersson, Johan Ahlström, Magnus Ekh and Lennart Josefson: Homogenization based macroscopic model of phase transformations and cyclic plasticity in pearlitic steel, *Journal of Thermal Stresses*, vol 45, issue 6, 2022, pp 470-492 (also listed under projects MU30 and MU39), doi.org/10.1080/01495739.2022.2056557

Björn Andersson, Magnus Ekh and Lennart Josefson: Computationally efficient simulation methodology for railway repair welding – Cyclic plasticity, phase transformations and multi-phase homogenization, *Journal of Thermal Stresses*, vol 47, issue 2, 2023, pp 164-188, doi.org/10.1080/01495739.2023.2283309

Björn Andersson: Thermo-mechanical-metallurgical modelling of pearlitic steels and railhead repair welding, Doctoral Dissertation, *Chalmers Industrial and Materials Science*, Gothenburg March 2024, 209 pp (Summary and five appended papers) research.chalmers.se/en/publication/540066

Björn Andersson, Erika Steyn, Magnus Ekh and Lennart Josefson: Simulation-based assessment of railhead repair welding process parameters, *Proceedings 22nd Nordic Seminar on Railway Technology*, Stockholm June 2024 (Summary and PowerPoint presentation)

Björn Andersson, Magnus Ekh and Lennart Josefson: Simulation-based assessment of railhead repair welding process parameters, *Welding in the World*, vol 69, 2025, pp 177-197 doi.org/10.1007/s40194-024-01837-y

MU38. GROWTH OF ROLLING CONTACT FATIGUE CRACKS

Tillväxt av sprickor vid rullkontaktutmattning

Project leader and supervisor	Professor Fredrik Larsson, Industrial and Materials Science / Division of Material and Computational Mechanics
Assistant supervisors	Professor Anders Ekberg and Professor Elena Kabo, Mechanics and Maritime Sciences
Doctoral candidate	Mr Mohammad Salahi Nezhad (from 2019-09-01; Lic Eng March 2022; PhD Aug 2024)
Period	2019-09-01 – 2024-06-30 (– 2024-08-31)
Chalmers budget (excluding university basic resources)	Stage 9: ksek 800 (+ 963 in S2R) Stage 10: ksek 1 230 (+ 2185 in S2R and ER) Stage 11: ksek 38 (+ 212 in ER)
Industrial interests in-kind budget	Stage 9: ksek 50 +50 + 50 + 0 + 200 Stage 10: ksek 50 + 50 + 50 + 30 +200 Stage 11: ksek 50 + 50 + 50 + 0 +200 *(Alstom + Lucchini + SweMaint + SYSTRA + voestalpine)*

PhD student Mohammad Salahi Nezhad (now PhD; second from the right) surrounded by (from the left) Professor Anders Ekberg, Professor Elena Kabo and Professor Fredrik Larsson in project MU38. Photo taken in 2021

Fatigue crack growth, particularly due to Rolling Contact Fatigue (RCF), is a major deterioration factor and one of the primary cost drivers in railway operations. Consequently, extensive research and development efforts have been dedicated to combating and predicting RCF. However, the effects of various operational factors on RCF initiation and growth remain largely unknown. Additionally, the quantification of the influence of different parameters is insufficient. While the overall risk of RCF initiation can be predicted to a large extent, predictions of the time to initiation and failure are subject to significant uncertainties. In particular, there are considerable uncertainties in predicting crack growth in terms of direction and rate of propagation.

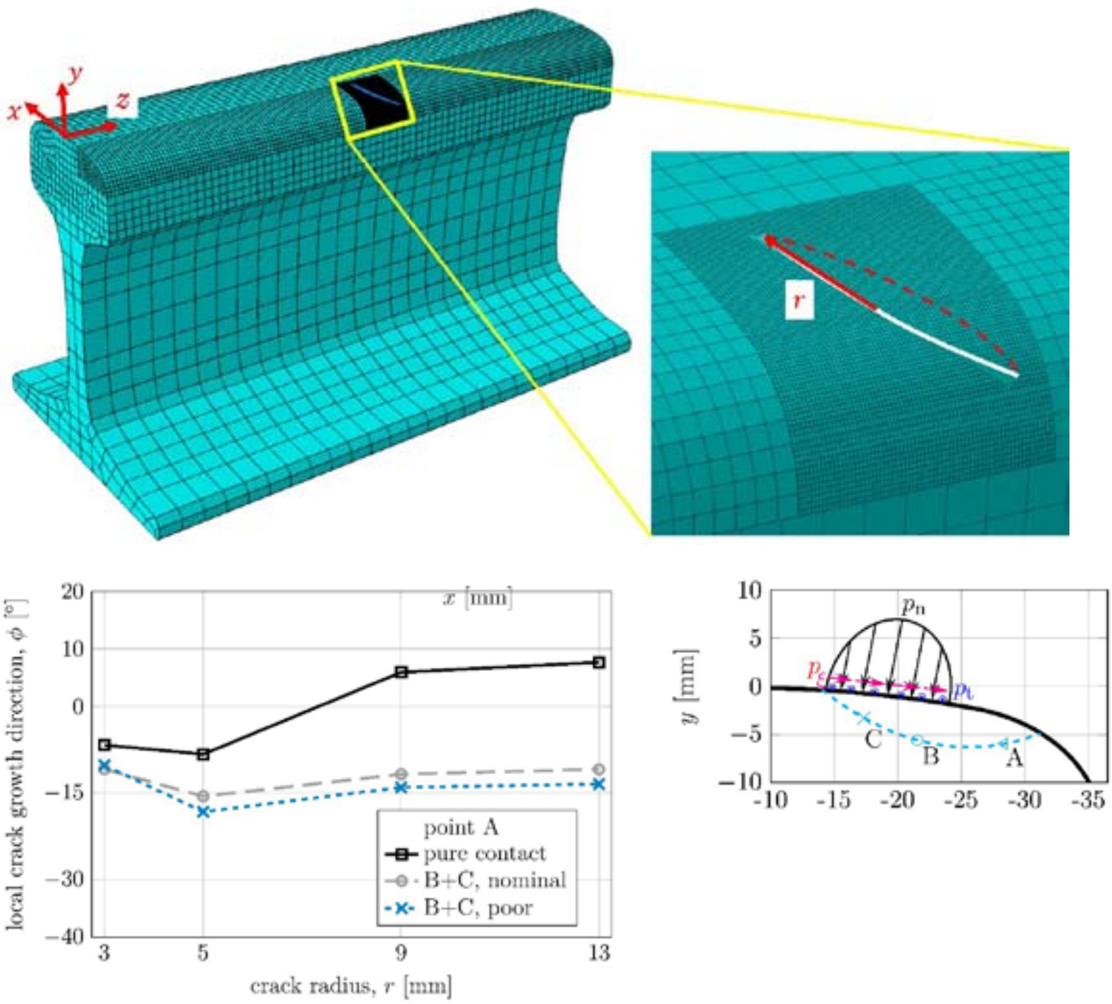
The aim of CHARMEC project MU38 was to investigate and develop methods for predicting crack progression in railway rails. This included both detailed analyses and coarser engineering approaches. Specifically, a numerical framework for predicting the growth of individual cracks during cyclic loading, corresponding to passing traffic, was developed based on finite element simulations in 2D and 3D. These models can be used to evaluate the influence of different operational parameters on the rate and direction of crack growth. Ultimately, once calibrated, they can assist in predicting the rate of deterioration in the field and how this is influenced by altered operational conditions. However, this will require additional work, including statistical variations in loads and the incorporation of a larger number of influencing factors, which are not accounted for in the current modelling setup.

The research has built upon results obtained in project MU33. Specifically, the accumulative criterion for predicting crack growth direction, previously developed and verified against experimental findings, was employed.

A numerical framework for an unbiased propagating crack in a 2D model was then developed to predict crack growth directions and rates. The predictions showed good agreement with experimental findings from a twin-disc experiment described in the literature, which are highly relevant for the wheel–rail contact situation in railway traffic. The influence of crack face friction was studied in 2D simulations. It was found that crack face friction typically promotes more downward growth and reduces the crack growth rate. Moreover, the wheel–rail contact load has a significant influence on the predictions, and as it cannot consistently be mapped to 2D, a 3D modelling is crucial for better qualitative and quantitative predictions.

The numerical framework was extended to 3D for a frictionless stationary crack in a model of a 60E1 rail. The influence of various operational parameters on crack growth direction and rate, as well as on fatigue rail life, was studied. Specifically, the varied parameters included crack size and inclination, magnitude and position of the contact load, wheel–rail tractive forces, rail bending with different track support conditions, and varying thermal loads. The predicted crack growth rates were found to reasonably match field observations reported in the literature. It was found that the location and magnitude of the contact load significantly influence predicted growth rates, and that the influence of a longitudinal tractive force decreases rapidly with depth. Additionally, rail life is reduced under combined load cases compared to the pure contact load case, as the combined

MU38. (cont'd)



The employed FE model for the 60E1 rail profile features a semi-circular surface-breaking inclined gauge corner crack of radius ***r*** (top). Three points A, B, and C along the crack front are monitored during the passing contact load (bottom right). An example of simulated crack growth directions, considering combined bending and contact loads and different track support conditions (nominal and poor), is presented (bottom left)

load cases exhibit higher crack growth rates. However, the ratio between contact and tensile thermal/rail bending load influences the propensity for downward crack growth under combined load cases.

Mohammad Salahi Nezhad presented his licentiate thesis (see below) at a seminar on 31 March 2022, where Professor Mårten Olsson from KTH Royal Institute of Technology introduced the discussion. Also, Mohammad Salahi Nezhad defended his doctoral dissertation (see below) on 30 August 2024, with Professor Roger Lewis from the University of Sheffield in the UK serving as the faculty-appointed external examiner. Mohammad Salahi Nezhad remained employed at Chalmers until November 2024 and continued his work in the Europe's Rail project IAM4RAIL (CHARMEC project EU23). For the joint reference group, see under project TS20.

Mohammad Salahi Nezhad, Dimosthenis Floros, Fredrik Larsson, Elena Kabo and Anders Ekberg: Numerical predictions of crack growth direction in a railhead under contact, bending and thermal loads, *Engineering Fracture Mechanics,* vol 261, 2022, 11 pp doi.org/10.1016/j.engfracmech.2021.108218

Mohammad Salahi Nezhad: Crack growth paths in rolling contact fatigue – Numerical predictions, Licentiate Thesis, *Chalmers Industrial and Materials Science*, Gothenburg, March 2022, 69 pp (Summary and two appended papers) research.chalmers.se/en/publication/528932

Mohammad Salahi Nezhad, Fredrik Larsson, Elena Kabo and Anders Ekberg: Numerical prediction of railhead rolling contact fatigue crack growth, *Wear*, vols 530–531, 2023, 14 pp (revised article from conference *CM2022*) doi.org/10.1016/j.wear.2023.205003

Mohammad Salahi Nezhad, Fredrik Larsson, Elena Kabo and Anders Ekberg: RCF crack propagation predictions, *Proceedings 22nd Nordic Seminar on Railway Technology*, Stockholm (Sweden) June 2024 (Summary and PowerPoint presentation)

Mohammad Salahi Nezhad: Numerical investigations of rolling contact fatigue crack growth in a rail head, Doctoral Dissertation, *Chalmers Industrial and Materials Science*, Gothenburg August 2024, 161 pp (Summary and four appended papers) research.chalmers.se/en/publication/542086

Mohammad Salahi Nezhad, Fredrik Larsson, Elena Kabo and Anders Ekberg: Finite element analyses of rail head cracks: Predicting direction and rate of rolling contact fatigue crack growth, *Engineering Fracture Mechanics*, vol 310, 2024, 16 pp doi.org/10.1016/j.engfracmech.2024.110503

MU39. NUMERICAL MODELLING OF MATERIAL DETERIORATION IN RAILWAY APPLICATIONS

Numerisk modellering av nedbrytning av material i järnvägstillämpningar

Project leaders	Professor Magnus Ekh and Professor Fredrik Larsson, Industrial and Materials Science / Division of Material and Computational Mechanics
Doctoral candidate	None (only senior researchers in this project)
Period	2018-06-01 – 2024-06-30 (– 2027-06-30)
Chalmers budget (excluding university basic resources)	Stage 9: kSEK 200 (+ 1 492 in S2R) Stage 10: kSEK 260 (+ 1 713 in S2R and ER) Stage 11: kSEK 610 (+ 540 in ER)
Industrial interests in-kind budget	Stage 9: kSEK 100 Stage 10: kSEK 100 Stage 11: kSEK 100 *(voestalpine)*

For a photo of Magnus Ekh and Fredrik Larsson, see page 49

This project is being run in parallel with our projects TS22, MU35, MU36, MU37, MU38, MU40 and MU41, with the dual purpose of increasing communication and interaction between the projects and improving numerical tools that can be used in current and future CHARMEC projects.

A ballast settlement model has been formulated and used for predicting long-term track settlements in TS22. The model is based on a viscoplastic material framework but is reformulated in terms of the settlement of ballast, and sleeper–ballast contact forces.

In MU35, non-proportional multiaxial fatigue crack propagation has been experimentally analysed. Specimens of predeformed pearlitic rail steel with a notch have been loaded. To ensure the same crack initiation location for both axial and torsional loading, the design of the notch was suggested based on finite element analyses. These analyses were performed in this project together with project MU35.

To simulate welding and other high-temperature processes in rail and wheel steels, followed by rolling contact fatigue loading, a combined cyclic plasticity and phase transformation model must be used. To allow for individual stress-strain models for the different phases of the material, homogenisation algorithms must be employed. An implementation of a self-consistent homogenisation algorithm has been performed, demonstrating high accuracy at a low computational cost when evaluated against other algorithms in project MU37.

Reduced-order modelling allows for faster numerical simulation of the wheel–rail contact. In conjunction with project MU40, such a technique has been developed using Proper Generalised Decomposition (PGD), demonstrating its applicability to the wheel–rail contact problem.

Workshops with the University of Leoben, voestalpine, Virtual Vehicle and CHARMEC have been arranged annually. Furthermore, this project has supported activities within the European projects In2Track3 and IAM4RAIL.

Björn Andersson, Johan Ahlström, Magnus Ekh and Lennart Josefson: Homogenization based macroscopic model of phase transformations and cyclic plasticity in pearlitic steel, *Journal of Thermal Stresses*, vol 45, issue 6, 2022, pp 470-492 (also listed under projects MU30 and MU37) doi.org/10.1080/01495739.2022.2056557

Kourosh Nasrollahi, Jens Nielsen, Emil Aggestam, Jelke Dijkstra and Magnus Ekh: Prediction of long-term differential track settlement in a transition zone using an iterative approach, *Engineering Structures*, vol 283, 2023, 16 pp (also listed under project TS22), doi.org/10.1016/j.engstruct.2023.115830

Daniel Gren, Johan Ahlström and Magnus Ekh: Fatigue crack characteristics in gradient predeformed pearlitic steel under multiaxial loading, *Advanced Engineering Materials*, vol 26, issue 19, 2024, 13 pp (also listed under projects MU30 and MU35) doi.org/10.1002/adem.202400950

Reindeer on track as viewed from locomotive, during winter testing of LL-brake blocks in project SD11, between Haparanda and Boden in February 2022

MU40. DIGITAL TWINS OF REPROFILED RAILS

Digital tvilling för omslipade räler

Project leader and supervisor	Professor Fredrik Larsson, Industrial and Materials Science / Division of Material and Computational Mechanics
Assistant supervisors	Professor Magnus Ekh and Professor Ragnar Larsson, Industrial and Materials Science, and Docent Björn Pålsson, Mechanics and Maritime Sciences
Doctoral candidate	Ms Caroline Ansin (from 2020-12-01; Lic Eng June 2023)
Period	2020-02-04 – 2024-06-30 (– 2025-11-30)
Chalmers budget (excluding university basic resources)	Stage 9: kSEK 250 (+ 254 in S2R) Stage 10: kSEK 1 530 (+ 2038 in S2R and ER) Stage 11: kSEK 940 (+ 830 in ER)
Industrial interests in-kind budget	Stage 9: kSEK 100 Stage 10: kSEK 250 Stage 11: kSEK 250 *(voestalpine)*

PhD student Caroline Ansin (front) surrounded by (from the left) Professor Ragnar Larsson, Professor Fredrik Larsson, Docent Björn Pålsson and Professor Magnus Ekh in project MU40

In curved railway tracks, the contact between wheel and rail often results in high tangential contact forces, which can cause damage to the rails such as wear, plastic deformation, or crack initiation and propagation due to Rolling Contact Fatigue (RCF). If not mitigated in time, this damage can eventually lead to rail failure, resulting in traffic interruptions or train delays. Therefore, the rail must be maintained, necessitating frequent physical inspections, grinding, or the installation of new rails, all of which are associated with high costs. Numerical simulations, in combination with field measurements, offer a promising approach for predicting rail damage, which can be used to optimise maintenance procedures.

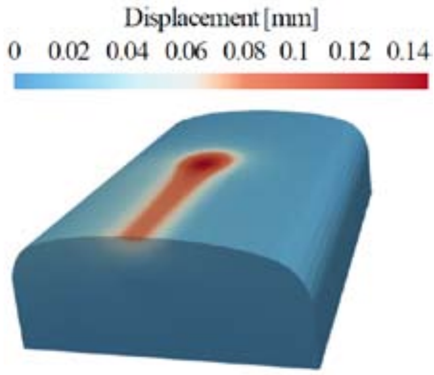
The aim of project MU40 is to develop a digital twin modelling framework for predicting rail damage evolution under operational traffic in a railway curve. The digital twin should provide accurate predictions of rail damage through fast and memory-efficient simulations that surpass real-time occurrences. Achieving this requires the development of computationally efficient numerical tools, such as a Reduced Order Model (ROM). The accuracy of the digital twin will continually be improved and validated through updates facilitated by field measurements. Ultimately, the goal is that the digital twin could serve as a decision-making support tool for rail maintenance regarding timing and action.

The digital twin predicts the evolution of representative rail cross-sections in a constant-radius section of a rail curve over time. This is achieved through feedback loops involving dynamic vehicle–track interaction, accounting for specific loading conditions, and the accumulative rail damage attributed to plasticity and surface wear to update the rail profile, as well as the initiation of cracks. Incorporating field measurements (eg, rail profiles using MiniProf) in these feedback loops allows for effective calibration of the model parameters. Validation is also ensured by comparing simulation results with experimental field data, thereby assessing the accuracy of the calibrated digital twin.

So far, two studies have been conducted on the digital twin. The first study compared predicted profile changes to field measurements for estimated operational conditions. A few sections along the Western Main Line in Sweden, with known traffic load and measured development of rail profile geometries, were studied. This enabled model calibration for average geometry changes, allowing for better predictions of future rail damage. Additionally, crack initiation was investigated, providing insights into where on the rail profile cracks initiate and the amount of traffic required for this to occur. In the second study, an analysis of wear distribution on rail profiles was undertaken to assess the impact of various model parameters. The inclusion of freight vehicles in the traffic mix and the utilisation of a varied set of measured wheel profiles in the simulation framework showed promising results, leading to a more spread-out wear distribution, which better resembles the measurements.

To improve numerical efficiency, a ROM has been developed. It combines Proper Generalised Decomposition (PGD) and fix-point iterations to simulate the elastic-plastic response in the rail beneath the wheel–rail contact under varying contact loads. This model is important for conducting cost-efficient simulations within the digital twin framework, particularly when managing high volumes of traffic.

MU40. (cont'd)



Simulation result from the reduced order model, predicting the elastic-plastic deformation in a rail under stationary rolling contact

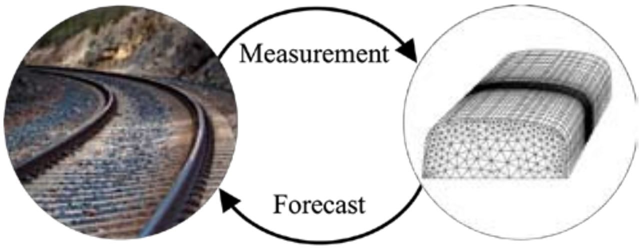


Illustration of the digital twin representing a railhead cross-section in a curved rail section. In the digital twin framework, the numerical model is continually updated with field measurements to improve the accuracy of the predictions of the material damage in the rail head

The project commenced in 2020, with PhD student Caroline Ansin being recruited in December 2020. Prior to this, Professor Ralf Jänicke was involved but subsequently left Chalmers University for a position at Technische Universität Braunschweig in Germany.

Caroline Ansin presented her licentiate thesis (see below) at a seminar on 5 June 2023, where Professor Mathias Wallin from Lund University introduced the discussion.

For the joint reference group, see under project TS20.

Caroline Ansin, Björn Pålsson, Magnus Ekh, Fredrik Larsson and Ragnar Larsson: Simulation and field tests of long term rail profile damage in a curve due to plasticity, wear and surface crack initiation, *Proceedings 21st Nordic Seminar on Railway Technology*, Tampere (Finland) June 2022 (Summary and PowerPoint presentation)

Caroline Ansin, Björn Pålsson, Magnus Ekh, Fredrik Larsson and Ragnar Larsson: Simulation and field measurements of the long-term rail surface damage due to plasticity, wear and surface rolling contact fatigue cracks in a curve, *Proceedings 12th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2022)*, Melbourne (Australia) September 2022, pp 591–601

Caroline Ansin and Björn Pålsson: Influence of model parameters on the predicted rail profile wear distribution in a curve, *Chalmers Industrial and Materials Science*, Gothenburg 2023, 8 pp

Caroline Ansin: Towards a digital twin for prediction of rail damage evolution in railway curves, Licentiate Thesis, *Chalmers Industrial and Materials Science*, Gothenburg May 2023, 93 pp (Summary and three appended papers)
research.chalmers.se/en/publication/535723

Caroline Ansin, Fredrik Larsson and Ragnar Larsson: Fast simulation of 3D elastic response for wheel–rail contact loading using Proper Generalized Decomposition. *Computer Methods in Applied Mechanics and Engineering*, vol 417, 2023, 22 pp
doi.org/10.1016/j.cma.2023.116466

Visit at Nordic Rail Fair on 11 October 2023. From the left: Caroline Ansin, Roger Lundén, Kourosh Nasrollahi (CHARMEC) and Tony Johansson (Vibisol / Wavebreaker)

MU41. CRACK INITIATION IN ANISOTROPIC WHEEL/RAIL MATERIAL

Sprickinitiering i anisotropt material hos hjul och rälmaterial

Project leader and supervisor	Professor Magnus Ekh, Industrial and Materials Science / Division of Material and Computational Mechanics
Assistant supervisors	Professor Johan Ahlström, Industrial and Materials Science, Dr Knut Andreas Meyer, TU Braunschweig / Industrial and Materials Science
Doctoral candidate	Ms Nasrin Talebi (from 2021-11-17; Lic Eng Aug 2024)
Period	2021-11-17 – 2024-06-30 (– 2026-11-16)
Chalmers budget (excluding university basic resources)	Stage 10: KSEK 815 (+ 1 477 in S2R and ER) Stage 11: KSEK 1 635 (+ 1 440 in ER)
Industrial interests in-kind budget	Stage 10: KSEK 250 Stage 11: KSEK 250 *(voestalpine)*

PhD student Nasrin Talebi surrounded by Dr Knut Andreas Meyer (left) and Professor Magnus Ekh (right) in project MU41

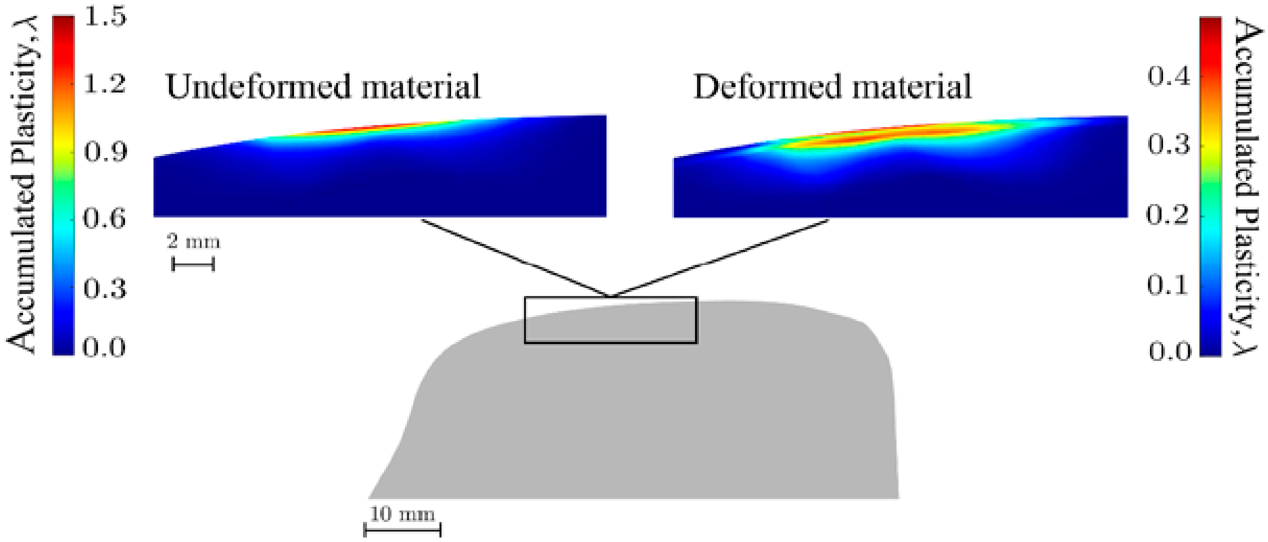
Rolling Contact Fatigue (RCF) crack initiation is often associated with the accumulation of plastic deformation in the surface layer of rails and wheels. The behaviour and strength of this highly deformed and anisotropic layer are thus key properties of rail and wheel materials. An experimental technique to analyse and measure these properties was developed and exploited in project MU34, where an axial-torsion testing machine was used to subject the material to loading conditions similar to RCF loading. Based on these experiments and on numerical models developed in MU34, the current project aims to exploit and further develop fatigue crack initiation criteria for the anisotropic material. Additional experimental studies will be carried out in co-operation with project MU35. Another important aim is to improve the modelling of the anisotropic material with respect to long-term cyclic and multiaxial loading. Throughout the project, the finite element method will be used to simulate rolling contact conditions, and a goal is to investigate how field measurements can be used to improve and validate the modelling.

The number of cycles to failure of highly deformed solid cylindrical test bars has been used to investigate the predictive capabilities of two commonly adopted RCF criteria in railway applications (Jiang-Sehitoglu and Kapoor). The finite element method was used together with a plasticity model (developed in MU34) to predict the inhomogeneous stress-strain conditions in the solid test bars. The RCF criteria were then applied to the stress and strain histories. From the results, it was concluded that the Kapoor criterion was not able to satisfactorily predict the number of cycles to failure. However, the Jiang-Sehitoglu criterion showed good agreement between the numerical and experimental data, although the identified parameter values differ from literature values for similar materials.

A continued evaluation of fatigue crack initiation criteria has been conducted by extending the considered experimental data to three groups: combined axial-torsion tests with large shear strain increments (pre-deformation), proportional multiaxial low-cycle fatigue experiments preceded by different levels of pre-deformation, and uniaxial high-cycle fatigue tests. Finite element simulations of the pre-deformation tests, using a finite-strain plasticity model accounting for isotropic, kinematic, and distortional hardening, provided local stress and strain predictions for the specimens. Based on the results, modified criteria have been proposed. A cross-validation approach has been adopted to examine the capability and reliability of both existing and proposed criteria. One of the proposed modifications noticeably reduced the fitting error while maintaining a similar prediction error. Furthermore, it also fit satisfactorily when all experimental data were included in the optimisation, indicating its potential for further improvements with the availability of more experimental data.

In another study, the impact of deformed near-surface material on the mechanical behaviour and fatigue crack initiation of a rail under in-service loading was investigated. Data from multiaxial low-cycle fatigue experiments under non-proportional loading at different levels of pre-deformation were used to calibrate an anisotropic plasticity model for different amounts of accumulated shear strain. The identified material parameter values were then used to account for spatially varying properties in a railhead.

MU41. (cont'd)



Accumulated plasticity in a rail head with an undeformed (left) or a deformed (right) surface layer after a loading sequence. The results show that the deformed surface layer acts as a protective layer, slowing down the rate of plasticity accumulation

This variation is governed by the fact that the data are from different pre-deformation levels, corresponding to measured shear strains in railhead field samples. Finite element simulations of a rail subjected to a realistic traffic sequence were conducted. The resulting stress-strain histories were used to evaluate the risk of fatigue crack initiation using the previously proposed crack initiation criterion. By comparing the results for a rail with deformed material to a rail with virgin material, it was shown that the deformed material significantly reduces the rate of fatigue damage growth. This highlights the importance of accounting for the deformed near-surface material in a railhead when predicting fatigue crack initiation.

The project MU41 has been presented and discussed during some of the biannual workshops with participants from the University of Leoben, voestalpine, and CHARMEC.

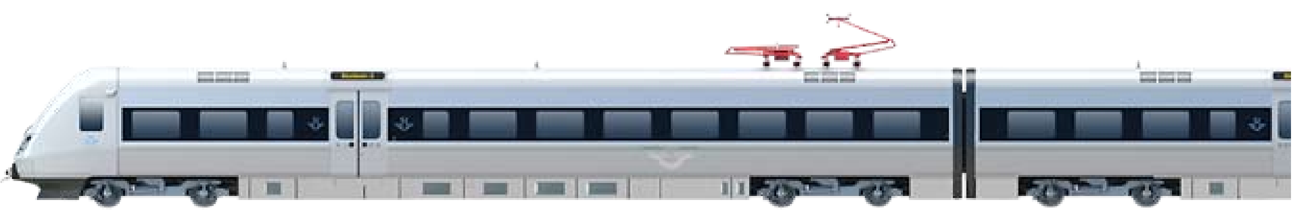
Nasrin Talebi presented her licentiate thesis (see below) at a seminar on 29 August 2024, where Senior Associate Professor Daniel Leidermark from Linköping University introduced the discussion. For the joint reference group, see under project TS20.

Nasrin Talebi, Johan Ahlström, Magnus Ekh and Knut Andreas Meyer: Crack initiation criteria for deformed anisotropic R260 rail steel, *Proceedings 21st Nordic Seminar on Railway Technology*, Tampere (Finland) June 2022 (Summary and PowerPoint presentation)

Nasrin Talebi, Johan Ahlström, Magnus Ekh and Knut Andreas Meyer: Crack initiation criteria for deformed anisotropic R260 rail steel, *Proceedings 12th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2022)*, Melbourne (Australia) September 2022, pp 857–864

Nasrin Talebi, Johan Ahlström, Magnus Ekh and Knut Andreas Meyer: Evaluations and enhancements of fatigue crack initiation criteria for steels subjected to large shear deformations, *International Journal of Fatigue*, vol 182, 2024, 12 pp (also listed under project MU30)
doi.org/10.1016/j.ijfatigue.2024.108227

Nasrin Talebi: Predicting rolling contact fatigue crack initiation in highly deformed rail steel, Licentiate Thesis, *Chalmers Industrial and Materials Science*, Gothenburg August 2024, 86 pp (Summary and two appended papers)
research.chalmers.se/en/publication/542275



A forerunner to this SJ 3000 train holds the Swedish high-speed record of 303 km/h. This record was achieved in 2008 during a testing activity within a research project in a collaboration between Trafikverket, Bombardier, SJ, KTH, and Chalmers. Courtesy: SJ

SD11. TREAD BRAKING – CAPACITY, WEAR AND LIFE

Blockbromsning – kapacitet, slitage och livslängd

Project leader and supervisor	Docent Tore Vernersson, Mechanics and Maritime Sciences / Division of Dynamics
Assistant supervisor	Professor Roger Lundén, Mechanics and Maritime Sciences
Doctoral candidate	Mr Eric Voortman Landström (from 2020-02-01; Lic Eng Nov 2022; PhD Jan 2025)
Period	2020-02-01 – 2024-06-30 (– 2025-01-31)
Chalmers budget (excluding university basic resources)	Stage 9: kSEK 1 490 + 600 Stage 10: kSEK 3 450 + 2572 (+ 207 + 193 in S2R and ER) Stage 11: kSEK 390 + 500 (+ 340 + 475 in S2R and ER)
Industrial interests in-kind budget	Stage 9: kSEK 50 + 100 + 100 + 0 + 50 + 170 Stage 10: kSEK 150 + 140 + 100 + 62 + 50 + 300 Stage 11: kSEK 30 + 30 + 30 + 20 + 20 + 200 *(Alstom + Green Cargo + Lucchini + SweMaint + SYSTRA + Wabtec)*

This is a combined doctoral and senior research project

Tread braking is a low-cost solution for trains where the braking requirements do not exceed the limits of this system. The limits relate to different aspects such as safety (global wheel failure, winter-related loss of braking efficiency), costs (wear of wheels and blocks, premature tread failure due to rolling contact fatigue (RCF)), health (particle emissions) and societal aspects (noise emissions). The aim of project SD11 is to acquire in-depth knowledge and establish limits for the commercial applications of tread brakes, addressing the requirements of today and the near future. The project encompasses tread braking for freight wagons, metros and commuter trains, with a focus on the sliding contact between wheel and brake block, and the rolling contact between wheel and rail. The primary knowledge gaps that the project aims to bridge concern: (i) simulation of global wheel behaviour at extreme temperatures, (ii) quantification of the influence of tread braking on the RCF life of the wheel, (iii) establishment of the temperature-dependence of tread wear, (iv) research into improved brake blocks for winter conditions with optimised material combinations, (v) extension of tread-braking wear models to include the modelling of particle emissions, and (vi) monitoring of brake blocks using Internet-of-Things concepts.

Dr Kazuyuki Handa (Researcher at Friction Materials Laboratory, RTRI) and Lic Eng Eric Voortman Landström. Photo taken during Eric Voortman Landström's stay at RTRI in Tokyo during spring 2024

Initially focusing on the behaviour of wheels at extreme temperatures, material models previously developed in project MU32 to mimic the wheel material ER7 steel have now been evaluated for their performance in mechanical simulations of freight wheels under constant power braking over long durations. The previous calibration procedure of the material models, which utilised only isothermal test data at several constant temperature levels, has been complemented by anisothermal materials testing of specimens. In this process, both temperature and strain variations in the test specimens, as provided by Lucchini RS in Italy, are simultaneously replicated to resemble those experienced during extreme tread braking. Based on the novel testing results provided in project MU36, the viscoplastic material model established in project MU32 has been modified to, e g, include the modelling of material damage. This specific modification captures the reduction in yield properties associated with pearlite breakdown at elevated temperatures. When employed for the simulation of severe tread braking events, the results from the modified material model were found to align well with experimental data and demonstrate significant improvement, exhibiting superior numerical convergence compared to previous generations of isothermally calibrated material models, which were quite unstable.

SD11. (cont'd)

Dr John Cookson, Professor Fredrik Larsson, Docent Sara Janhäll (RISE / Chalmers), Adjunct Professor Peter Skoglund (Scania / Linköping University), Professor Sebastian Stichel (KTH), Dr Eric Voortman Landström, Mr Jan Möller, Professor Roger Lundén, Docent Tore Vernersson and Professor Anders Ekberg after the doctoral examination in project SD11 on 24 January 2024

In parallel, work on establishing a brake test rig at the Chalmers premises has been ongoing since spring 2020, see project SP34. The brake rig and its functionality, which in its final configuration includes a rail-wheel in rolling contact with the tread-braked wheel, have been instrumental for the work in project SD11. Experimental results have been important in developing new knowledge and numerical models during the current stage, particularly regarding global wheel behaviour at extreme braking temperatures. During this work, it was discovered that global unevenly distributed temperatures develop over the wheel rim during brake test rig experiments, with tread temperatures potentially exceeding the average tread temperature by more than 100 °C. This finding necessitated further numerical investigations into the effects of local heating on wheel rim performance, as well as additional experimental campaigns. For brake rig testing, global uneven temperatures primarily appeared during braking at power levels between 20 and 40 kW per wheel, although they were also observed to some extent at 50 kW. Numerical simulations showed that temperature variations induced by smaller hot spots have minor effects on average residual stresses in the wheel rim, whereas larger hot spots and global uneven temperatures have a substantial impact.

A field study on wheel temperatures in iron ore trains on Ofotbanen (at Straumsnes near Narvik, Norway), with special support from LKAB and Bane NOR, confirmed that global uneven temperatures can also be found in revenue traffic, although the observed temperature differences were smaller (up to 80 °C). It was found that only one out of every few hundred wheels showed significant thermal localisation, although it was more frequent in the wheels with the highest temperatures (up to one in eight for wheels with an average rim temperature higher than 220 °C). It was suspected that the stiffness of the wheel–brake interaction might be the cause of the phenomenon, and for this reason, a device for controlling this stiffness has been designed for implementation in the brake test rig.

Additionally, particle emission measurements have been carried out during several of the brake rig tests in collaboration with Docent Jonas Sjöblom of Chalmers Division of Transport, Energy and Environment. The aim was to collect representative particles from the tests and to initiate research into brake emissions.

In the project's concluding six-month period, the emphasis was redirected towards investigating rolling contact and the temperature-induced effects on RCF and tread wear. A numerical model for simulating rolling contact during braking was developed, employing the viscous material model established earlier in the project. The primary objective of this model was to evaluate performance under high strain-rate rolling contact conditions. The model demonstrates promising results for simulating rolling contact by predicting elastic shakedown after a few cycles at low temperatures and ratchetting at high temperatures.

Thermographic image of a tread-braked wheel during braking. Note mirror to the left, providing view of the tread

SD11. (cont'd)

The brake test rig at Chalmers was mechanically upgraded to incorporate the planned rail-wheel, which can be controlled with respect to both lateral position and yaw angle when in rolling contact with the braked wheel. Furthermore, an additional motor was incorporated to provide a traction force to replicate the braking force in the wheel–rail contact, which is known to be important for RCF crack initiation. Initial tests with a low tractive force and a fixed lateral position of the rail-wheel demonstrated that the wheel tread was subjected to global plastification rather than crack initiation, resulting in a trough in the tread. It is hypothesised that subsequent experimentation, incorporating a higher tractive force in conjunction with a time-varying lateral position of the rail-wheel, will yield insights into the initiation of RCF cracks.

Lorenzo Ghidini, a doctoral student at the University of Brescia, Italy, spent three months at Chalmers in spring 2023 and another month in the autumn, working on thermal modelling of a novel small-scale testing machine for studying the effects of simultaneous tread braking and rolling contact, see pages 80 and 87. Eric Voortman Landström was guest researcher at the Railway Technical Research Institute (RTRI) in Tokyo, Japan, for three months in spring 2024, working on thermomechanical testing of wheels during stop braking, see pages 53 and 64, in addition to providing technical assistance with the ultrasonic residual stress measurement device Debbie. Work on a joint paper chronicling the tests was presented in Eric's doctoral dissertation, with an additional paper on numerical simulations anticipated.

Eric Voortman Landström presented his licentiate thesis (see below) at a seminar on 22 November 2022 where Mr Peter Nyström of RCON introduced the discussion. Additionally, Eric Voortman Landström successfully defended his doctoral dissertation (see below) on 24 January 2025. The faculty-appointed external examiner was Dr John Cookson from Monash University, Melbourne, Australia.

Eric Voortman Landström continues his employment at Chalmers as a postdoctoral researcher and is involved in project SD12 and the Europe's Rail project IAM4RAIL (CHARMEC project EU27).

Since 2022, Tore Vernersson has been involved in the UIC sector project "Brake blocks wheel interaction" as the convenor of the working group responsible for the activity "Wheel design worst case scenario assessment". This activity is part of a work package that specifies the state-of-the-art and details the numerical and experimental work to be performed in a subsequent work package, in which further involvement of CHARMEC is anticipated. The overall aim of the sector project is to define appropriate conditions for managing the interaction between brake blocks and wheel, preventing safety risks and restrictions in the use of tread-braked wheels. This will improve the reliability of the rail system, and enhance standards and regulations to avoid approaches based on singular experience. This work received separate funding from UIC.

Tore Vernersson has continued to be involved in the work on winter tread braking performance of composite brake blocks. He was initially involved in the planning and data analyses of winter field tests conducted by Transportstyrelsen (The Swedish Transport Agency) to assess the performance of LL brake blocks in winter conditions between 2018 and 2021 (reports are available on the Transportstyrelsen home page, see below). Since 2023, he has been part of a Swedish group of experts working for Transportstyrelsen with the aims of: (i) assessing past winter-related work on composite blocks that has led to the present composite brake block types homologated for freight traffic, (ii) identifying possible deficiencies in this work, and (iii) improving the requirements for homologation tests of composite brake blocks. These projects receive separate funding from Transportstyrelsen.

Tore Vernersson, Anders Ekberg and Roger Lundén: Swedish tests of LL brake blocks under winter conditions – Winter 2020-2021 (Report for The Swedish Transport Agency), *Chalmers Mechanics and Maritime Sciences* / CHARMEC, 2021, 93 pp
(Further reports are found on www.transportstyrelsen.se/sv/om-oss/publikationer-och-rapporter/rapporter/rapporter-inom-jarnvag/riskbedomning-avseende-bromsblock-av-komposit-under-svenska-vinterforhallanden/)

Eric Voortman Landström, Tore Vernersson and Roger Lundén: Improved modelling of tread braked wheels using an advanced material model, *Proceedings International Braking Technology Community & Event (Eurobrake 2022)*, online, May 2022, 8 pp

Eric Voortman Landström, Tore Vernersson and Roger Lundén: Improved modelling of tread braked wheels using an advanced material model and brake rig tests, *Proceedings 21st Nordic Seminar on Railway Technology*, Tampere (Finland) June 2022 (Summary and PowerPoint presentation)

Tore Vernersson and Roger Lundén: Tread braking and winter conditions, *ibidem* (Summary and PowerPoint presentation)

Roger Lundén, Tore Vernersson and Mandeep Singh Walia: Wear of wheel treads and brake blocks at railway tread braking, *ibidem* (Summary and PowerPoint presentation)

Eric Voortman Landström, Erica Steyn, Johan Ahlström and Tore Vernersson: Thermomechanical testing and modelling of railway wheel steel, *International Journal of Fatigue*, vol 168, 2023, 11 pp (also listed under projects MU30 and MU36) doi.org/10.1016/j.ijfatigue.2022.107373

Eric Voortman Landström: Thermomechanical behaviour of tread braked wheels – Material modelling and experimental investigations, Licentiate Thesis, *Chalmers Mechanics and Maritime Sciences*, Gothenburg November 2022, 100 pp (Summary and three appended papers), research.chalmers.se/en/publication/532753

SD11. (cont'd)

Eric Voortman Landström, Tore Vernersson and Roger Lundén: Improved finite element modelling of tread braked wheel performance verified by brake rig tests, *Proceedings 20th International Wheelset Congress*, Chicago IL (USA), May 2023, pp 125-130

Eric Voortman Landström, Tore Vernersson and Roger Lundén: Analysis and testing of tread braked railway wheel – Effects of hot spots on wheel performance, *International Journal of Fatigue*, vol 180, 2024, 14 pp, doi.org/10.1016/j.ijfatigue.2023.108116

Eric Voortman Landström, Tore Vernersson and Roger Lundén: Thermomechanics of the brake-wheel-rail system – Results from two tread brake roller rigs, *Proceedings 22nd Nordic Seminar on Railway Technology*, Stockholm (Sweden) June 2024 (Summary and PowerPoint presentation)

Eric Voortman Landström, Matheus de Lara Todt, Tore Vernersson and Roger Lundén: Non-uniform temperature and residual stress effects during railway tread braking, *Chalmers Mechanics and Maritime Sciences*, Gothenburg 2024, 28 pp (revised version to be submitted for publication)

Eric Voortman Landström, Ryo Ozaki, Kazuyuki Handa and Tore Vernersson: Thermomechanical contact behaviour of tread braked wheels, *Chalmers Mechanics and Maritime Sciences*, Gothenburg 2024, 35 pp (revised version to be submitted for publication)

Eric Voortman Landström and Tore Vernersson: Numerical study of rolling contact fatigue at tread braking conditions, *Chalmers Mechanics and Maritime Sciences*, Gothenburg 2024, 28 pp (revised version to be submitted for publication)

Eric Voortman Landström: Thermomechanics of tread braking – Braking capacity of railway wheels, Doctoral Dissertation, *Chalmers Mechanics and Maritime Sciences*, Gothenburg December 2024, 257 pp (Summary and seven appended papers) research.chalmers.se/en/publication/544445

Eric Voortman Landström, Tore Vernersson and Roger Lundén: Characterisation and evaluation of global uneven heating during railway tread braking – Brake rig testing and field study, *IMechE Journal of Rail and Rapid Transit*, vol 239, issue 3, 2025, pp 258-271 doi.org/10.1177/09544097241312943

Robin Rydbergh, Lisa-Marie Witte, Jonas Sjöblom, Nathalie Scheers, Amir Saeid Mohammadi, Eric Voortman Landström and Tore Vernersson: ToF-SIMS analyses of brake wear particles in human epithelial Caco-2 cells, *Journal of Aerosol Science*, 2025, 19 pp, doi.org/10.2139/ssrn.4862316

SD12. HOLISTIC SIMULATIONS OF WHEEL TREAD LIFE BASED ON FIELD AND RIG TESTING

Holistiska simuleringar av livslängden hos hjulens löpbana baserade på fält- och riggmätningar

This doctoral project commenced early in Stage 11, and only a brief report is provided here. Mr Matheus de Lara Todt was employed as a PhD student in the project on 1 September 2024. Docent Tore Vernersson, Professor Roger Lundén and Docent Björn Pålsson are his supervisors. Project SD12 concerns wheel tread damage (wear, RCF, thermal cracks, etc), which is a major cost driver for trains. Test results from our novel brake-roller-rig test facility, see project SP34, will be combined with results from instrumented freight wagons to analyse the cost and degradation of wheels and rails in situations where wheel–rail adhesion controls the braking, with anticipated situations involving stronger braking. The aim of this new project is to develop, calibrate, and validate a holistic simulation model for predicting wheel tread damage using numerical modelling that has been validated through brake-roller-rig testing and results from field tests. The model should consider: (i) operating conditions, such as climate, mileage, braking strategies, etc, (ii) wear and damage caused by the contact between wheels and rails, and (iii) various braking systems. The focus will be on the impact of tread braking.

PhD student Matheus de Lara Todt in project SD12

EU21. In2Track3

In2Track3 – Research into Optimised and Future Railway Infrastructure

Project leader	Professor Anders Ekberg, Mechanics and Maritime Sciences / Division of Dynamics
Co-workers	The project engaged most of the staff at CHARMEC
Period	2021-01-01 – 2023-12-31
Budget Trafikverket/EU	Stage 9: kSEK 1 840 Stage 10: kSEK 32 104
Budget Chalmers	Stage 9: kSEK 0 Stage 10: kSEK 2 384

Pernilla Edlund from Trafikverket and Anders Ekberg in the tunnel leading to the new underground West Link station at Gothenburg Central Station

In2Track3 (S2R-CFM-IP3-01-2020) was a project within the Horizon 2020 Framework Programme under the Shift2Rail Joint Technology Initiative, with a project value of MEUR 26.7, including MEUR 11.8 in EU funding. The overall project co-ordinator was Trafikverket, with Pernilla Edlund of Trafikverket as the co-ordinator and CHARMEC's Anders Ekberg serving as the scientific and technical co-ordinator. The official website of the project is projects.shift2rail.org/s2r_ip3_n.aspx?p=IN2TRACK3

The eight work packages (WPs) in In2Track3 were: WP1 Enhanced S&C system demonstrator, WP2 Next generation switches & crossings demonstrator, WP3 Enhanced track, WP4 Next generation track, WP5 Assessment and improvement of tunnels and bridges, WP6 Project management, WP7 Technical co-ordination and scientific quality assurance, and WP8 Dissemination, exploitation and communication. CHARMEC was involved in WP1, WP2, WP3, WP7, and WP8. During the project, 18 additional subprojects were carried out and reported, and are included in the budget.

The official starting date for the project was 1 January 2021. CHARMEC's work in the first half-year of the project is presented in the Triennial Report of Stage 9. Our contributions to In2Track3 involved work from several parallel CHARMEC projects. The corresponding activities in In2Track3 are presented under these projects. Only co-ordination and additional research activities are reported below.

The project formally ended on 31 December 2023. All remaining deliverables were finalised and submitted by the end of 2023. The project is summarised in a Concluding Technical Report, to which CHARMEC's researchers have contributed 18 (of 79) chapters.

CHARMEC researchers chaired and/or participated in numerous Task and WP meetings. Anders Ekberg chaired all meetings of the Technical Management Team. These meetings were primarily held online.

An online mid-term review of In2Track3 was conducted by the Shift2Rail Joint Undertaking on 21 April 2022. Anders Ekberg participated from CHARMEC in his role as scientific and technical co-ordinator.

At the consortium meeting held on 15–16 June 2022 in Gothenburg, most CHARMEC researchers involved in In2Track3 participated, and several of our research findings were presented.

A technical meeting for WP3 Enhanced track was held in Amersfoort, The Netherlands, on 18–19 January 2023. During the meeting, 33 presentations were given by 13 In2Track3 partners. Chalmers/CHARMEC was represented by 11 researchers who contributed 10 presentations.

Björn Pålsson and Astrid Pieringer presented "Digital twin solution for crossing panels" and "Track design and maintenance guidelines to reduce curve squeal", respectively, in the webinar "Digital solutions for railways" on 18 October 2023. Anders Ekberg presented the work in EU21 as input to Europe's Rail at a seminar arranged by Trafikverket at KTH on 24 November 2023. The In2Track3 final event at Hotel Amaranten in Stockholm on 29–30 November 2023 featured 70 physical and 80 online participants and 9 presentations by CHARMEC researchers.

Track Buckling

Elena Kabo and Anders Ekberg conducted research on track buckling. The developed framework categorised the influence of parameters, such as curve radius and hanging sleepers, in terms of "equivalent temperature increases". The integration of this framework into Trafikverket's risk estimation frameworks was discussed in meetings with Trafikverket. The framework was employed to estimate risks following a major derailment repair on the Iron Ore

EU21. (cont'd)

Line in December 2023. The research was also presented at the 21st Nordic Seminar on Railway Technology and published in a scientific paper, see below.

Wheel impact and rail breaks

A model for predicting the risk of rail breakage induced by wheel impact loading was developed. Multiple stochastic variables, such as dynamic wheel load, rail crack depth, and fracture toughness, were simultaneously considered by generating a metamodel of the stress intensity at the crack. Data for the distribution of crack depths in selected curve radius intervals on the Iron Ore Line were assembled from Trafikverket's Optram. The risk of a rail break was found to increase with decreasing sleeper support stiffness. The methodology can be applied to specify alarm limits in terms of maximum allowed impact load, as well as rail monitoring and maintenance strategies. For example, measured peak loads were utilised in predictions, indicating that the risk of a rail break induced by freight traffic at an axle load of 20 tonnes was higher than that for iron ore traffic at an axle load of 30 tonnes, owing to a greater prevalence of out-of-round wheels in the 20-tonne traffic.

Results from the work were presented at the CM2022 conference, the 21ST Nordic Seminar on Railway Technology, and in a scientific paper, see below. An invited state-of-the-art paper on out-of-round wheels, including a discussion on the international approach to wheel impact load detectors and alarm limits, was presented at the International Symposium on Vehicle System Dynamics, see project TS8.

Slab track

Based on the European standard 16432-2 and considering the environmental impact, an optimised slab track design was developed. The design was applied in dynamic vehicle–track interaction simulations to calculate reinforcement stresses and crack widths, and to assess the impact of concrete cracks on the dynamic track response. The dynamic response and environmental impact were compared between traditional and innovative railway track systems, using both life cycle analysis (LCA) and a methodology for simulating three-dimensional vertical dynamic vehicle–track interaction.

Switches & crossings

Two measurement campaigns related to switches & crossings (S&C) were conducted. The first involved scanning three full crossing rails using a laser scanner at Trafikverket's crossing storage in Sannahed to obtain the exact rail geometry, and thus the stiffness and mass properties of the crossings as they are manufactured. The second measurement concerned the influence of trapped foreign objects on switch operations. By inserting spacers of different sizes and at different locations between the switch and stock rails, the conditions under which the switch goes in control with drives and rail gauge sensors were studied.

Grinding

An overview report on grinding and milling, titled "Rail machining strategies" by Erika Steyn, Björn Paulsson and Anders Ekberg, was compiled. It was sent to the UIC-TEG for review, and a condensed version was published as a scientific paper.

Brake test rig

The brake test rig, developed within the scope of project SP34 to provide specific experimental support for project SD11 and future projects, received funding from an additional subproject of In2Track3. Consequently, the planned rail-wheel module could be developed, and components procured and assembled. Additionally, targeted funding was allocated for the acquisition of a state-of-the-art thermographic camera, enabling the investigation of thermo-mechanical phenomena during braking.

Emil Aggestam, Jens Nielsen, Karin Lundgren, Kamyab Zandi and Anders Ekberg: Optimisation of slab track design considering dynamic train–track interaction and environmental impact, *Engineering Structures*, vol 254, 2022, 15 pp doi.org/10.1016/j.engstruct.2021.113749

Emil Aggestam: Comparison of the dynamic response and environmental impact between traditional and innovative railway track systems, *International Journal of Rail Transportation*, vol 11, issue 5, 2023, pp 685-704, doi.org/10.1080/23248378.2022.2099992

Jens Nielsen and Anders Ekberg: Simulation-based evaluation of the probability of rail break due to out-of-round wheel loads, *Proceedings 12th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2022)*, Melbourne (Australia) September 2022, 10 pp

Elena Kabo and Anders Ekberg: Estimating risks of track buckling, *Proceedings 21st Nordic Seminar on Railway Technology*, Tampere (Finland) June 2022 (Summary and PowerPoint presentation)

Jens Nielsen, Thomas Abrahamsson and Anders Ekberg: Probability of rail break due to wheel–rail impact loads, *ibidem* (Summary and PowerPoint presentation)

Emil Aggestam and Jens Nielsen: Comparison of the dynamic response between traditional and innovative railway track systems, *ibidem* (Summary and PowerPoint presentation)

Jens Nielsen and Anders Ekberg: Probability of rail break caused by out-of-round wheel loads, *Engineering Structures*, vol 294, 2023, 14 pp, doi.org/10.1016/j.engstruct.2023.116717

Erika Steyn, Björn Paulsson, Anders Ekberg and Elena Kabo: Rail machining – Current practices and potential for optimization, *IMechE Journal of Rail and Rapid Transit*, vol 238, issue 2, 2024, pp 196–205 (also listed under projects MU22 and MU36) doi.org/10.1177/09544097231187978

EU21. (cont'd)

Emil Aggestam, Anders Ekberg and Jens Nielsen: Innovative requirements and evaluation methods for slab track design. *IMechE Journal of Rail and Rapid Transit*, vol 238, issue 6, 2024, pp 651-661 (also listed under project TS8) doi.org/10.1177/09544097231218297

Elena Kabo and Anders Ekberg: Characterisation of track buckling resistance, *IMechE: Journal of Rail and Rapid Transit*, vol 238, issue 7, 2024, pp 786-794 doi.org/10.1177/09544097241231884

Pernilla Edlund and Anders Ekberg (Eds): In2Track3 – Concluding Technical Report, *Trafikverket*, ISBN 978-91-8045-358-5, 2024, 210 pp, research.chalmers.se/publication/543721

DELIVERABLES

Deliverables with CHARMEC contributions are listed below. Anders Ekberg reviewed all deliverable reports, as well as reports on additional work, in WPs 1–5.

D1.1 Enhanced S&C system midterm report

D1.2 Scientific methods and technical concepts on enhanced switches & crossings

D1.3 Enhanced S&C system final report

D2.4 Next generation S&C integration and installation into industry relevant environment

D3.1 Midterm report, Optimised track maintenance

D3.2 Midterm report, Wheel/rail interaction, simulations and track monitoring

D3.3 Optimised track maintenance

D3.4 Wheel/rail interaction, simulations and track monitoring (also listed under project SP37)

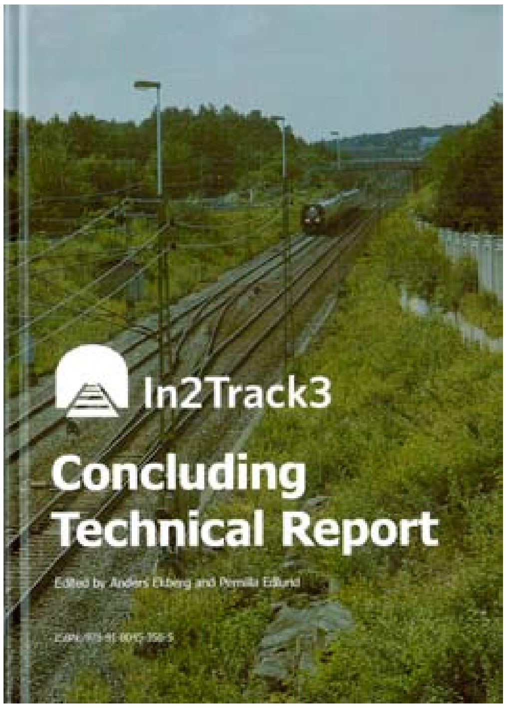
D6.2 Quality assurance report

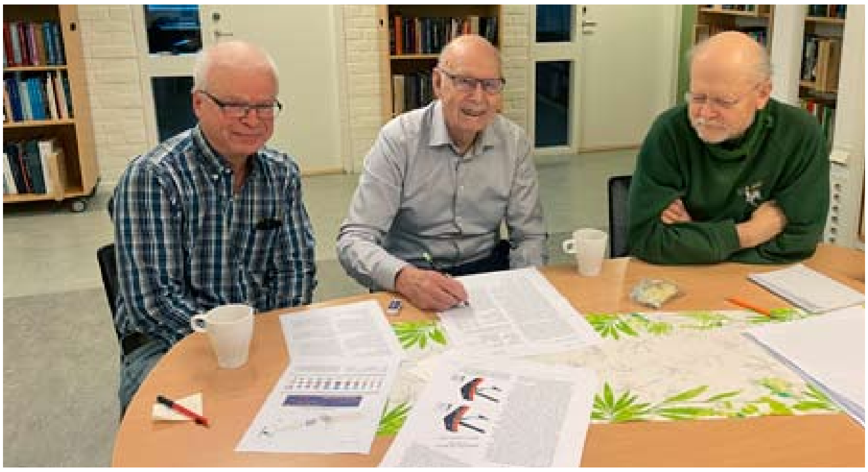
D7.1 Report on quality assurance activities and follow-up on research progress

D8.2 Data management plan

CONCLUDING TECHNICAL REPORT

This report, comprising 210 pages, was compiled by Anders Ekberg of CHARMEC and Pernilla Edlund of Trafikverket, with layout and production managed by Pernilla Edlund. It provides an overview of the In2Track3 project, including its background, objectives, participants, dissemination, challenges, and benefits. This is followed by 52 chapters detailing the research and results on Switches and Crossings, Track, Wheel/Rail Interaction, Bridges and Tunnels, and Demonstrators. Additionally, it lists all 29 deliverables, 67 scientific papers, 8 doctoral dissertations, and 2 licentiate theses related to In2Track3. The report is available online, see above.





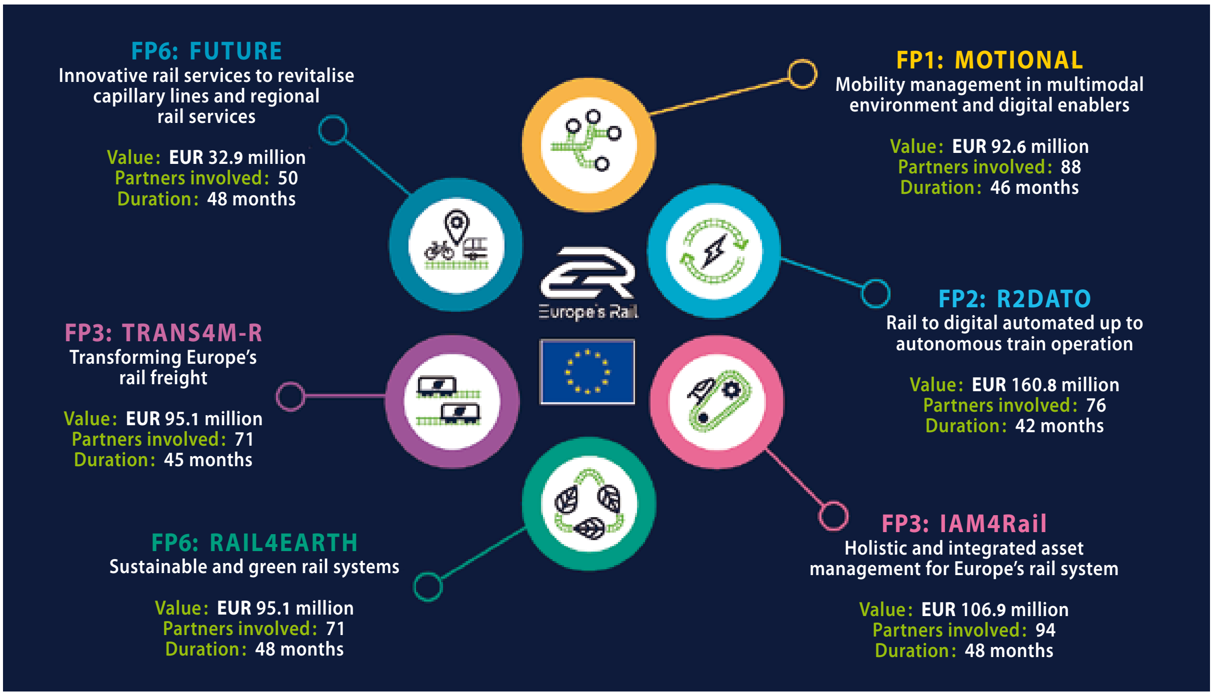
From the left: Roger Lundén, Bengt Åkesson and Tomas Wahlberg doing editing and layout work in March 2022

EUROPE'S RAIL

The Europe's Rail (ER) Joint Undertaking is the European partnership for rail research and innovation under the Horizon Europe programme (2020-2027) and the successor to Shift2Rail. The mission of ER is to deliver, via an integrated system approach, an EU railway network that is flexible, multimodal, sustainable, reliable, high-capacity, and integrated (Single European Railway Area). The total budget is MEUR 582 for the period 2022-2027. It includes seven flagship areas with different themes containing flagship projects, plus smaller focused projects. CHARMEC is involved in five of the ongoing flagship projects (FP) with a total budget of around MEUR 2.0. CHARMEC is working together with Trafikverket in all five of these FPs (CHARMEC projects EU22-26), and with voestalpine in one of them (CHARMEC project EU27). Due to extensions of the work in In2track3 under Shift2Rail, CHARMEC's start in ER was delayed and began in full in January 2024.

In the following, a brief description of each FP, along with a brief description of CHARMEC's involvement in the different FPs is given. Descriptions of the efforts together with Trafikverket are given first, followed by the one with voestalpine. Mostly, CHARMEC's contribution to the EU-projects is in collaboration with regular CHARMEC projects.

Europe's Rail Flagship Projects during Phase 1 of the research programme. Picture from rail-research.europa.eu



EU22. R2DATO

R2DATO – Rail to Digital Automated up to Autonomous Train Operation

Project leader	Professor Anders Ekberg, Mechanics and Maritime Sciences / Division of Dynamics
Period	2024-01-01 – 2024-06-30 (– 2026-05-31)
Budget	Stage 10: kSEK 276
Trafikverket / EU	Stage 11: kSEK 3 828
Budget Chalmers	Stage 10: kSEK 33
	Stage 11: kSEK 260

In R2DATO, the focus is on the digitalisation and automation of Europe's rail system, aiming to develop the Next Generation Automatic Train Control and deliver scalable automation in train operations to enhance infrastructure capacity on existing rail networks. Of the 48 Work Packages in R2DATO, CHARMEC researchers are active in six. In WP7, Data Factory Specifications and Implementation, the work involves identifying and evaluating useful data that can be collected and employed by an automatically operated train. WP27, Digital Register Specification, Development and Implementation, relates to WP7. WP17/18, Next Generation Brake Systems with Adhesion Management Functions, focuses on specifications for control and management of adhesion control in the context of Next Generation Brakes. WP34/35, Testing, Validation and Certification, involves the development of digital twin models for switches and crossings based on requirements for various virtual certification tasks.

EU23. IAM4RAIL

IAM4RAIL – Holistic and Integrated Asset Management for Europe's Rail System

Project leader	Professor Anders Ekberg, Mechanics and Maritime Sciences / Division of Dynamics
Period	2024-01-01 – 2024-06-30 (– 2026-11-30)
Budget Trafikverket / EU	Stage 10: kSEK 2 853 Stage 11: kSEK 9 654
Budget Chalmers	Stage 10: kSEK 125 Stage 11: kSEK 768

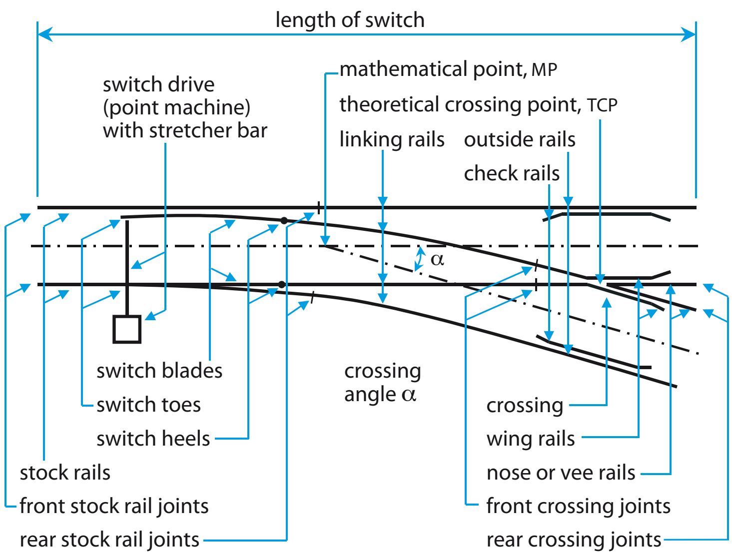
In IAM4RAIL, the focus is on integrating information on asset condition obtained via advanced monitoring with decision-making tools, and further into the traffic management system. Other topics, such as interventions using technologies like robotics or additive manufacturing, are considered relevant for improving asset management in the rail sector. Of the 21 Work Packages in IAM4RAIL, CHARMEC researchers are active in three, in collaboration with Trafikverket. WP8, Long-term Asset Management and LCC, involves CHARMEC's largest contribution to ER. The work includes studies on track buckling, differential track settlement in transition zones and plain line track, optimisation of fixed crossings, controlled experiments on rolling contact fatigue (RCF) crack propagation, and the development of a digital twin for rail reprofiling. In WP16, Sustainable and Cost-efficient Eco-design for Rail Assets, CHARMEC will focus on test methods for rail steel, including the characterisation and modelling of the anisotropic material properties in the deformed rail surface. In WP18, Robotics Platform, CHARMEC will work on identifying and evaluating tasks suitable for a track-based automated robot.

EU24. RAIL4EARTH

RAIL4EARTH – Sustainable and Green Rail Systems

Project leader	Professor Jens Nielsen, Mechanics and Maritime Sciences / Division of Dynamics
Period	2024-01-01 – 2024-06-30 (– 2026-11-30)
Budget Trafikverket / EU	Stage 10: kSEK 140 Stage 11: kSEK 1 167
Budget Chalmers	Stage 10: kSEK 2 Stage 11: kSEK 91

RAIL4EARTH covers the sustainable and green rail system, including rolling stock, infrastructure, stations, and their sub-systems. The project addresses the decarbonisation of diesel trains, noise and vibration reduction, energy saving, circular economy, resource consumption, resilience to climate change, and the attractiveness of passenger trains. Of the 29 Work Packages in RAIL4EARTH, CHARMEC researchers are active in WP3, Noise and Vibrations. This involves comparing models for the simulation of differential settlement in a benchmark case study and investigating methods for mitigating curve squeal.



Sketch of a right-hand railway turnout with terminology for "switch and crossing work" according to the European standard EN 13232-1 of September 2003. The tangent of the turnout angle is usually given, e g, tan α = 1:9 or 1:12. Often one of the terms "switch" or "turnout" is used for the complete structure consisting of the so-called switch, closure and crossing panels. Switches are sometimes referred to as "points"

EU25. TRANS4M-R

TRANS4M-R – Transforming Europe‘s Rail Freight

Project leader	Docent Björn Pålsson, Mechanics and Maritime Sciences / Division of Dynamics
Period	2024-01-01 – 2024-06-30 (– 2026-03-31)
Budget Trafikverket / EU	Stage 10: kSEK 665 Stage 11: kSEK 2 788
Budget Chalmers	Stage 10: kSEK 13 Stage 11: kSEK 234

TRANS4M-R's overarching goal is to establish rail freight as the backbone of a low-emission, resilient European logistics chain that fully satisfies end-user requirements. Digital Automatic Coupler (DAC) enabled solutions are integrated with software-defined systems and digital rail services to increase capacity and strengthen cross-border co-ordination. Of the 34 Work Packages in TRANS4M-R, CHARMEC researchers are active in three. In WP16, TRV/NRD Demo Train II, CHARMEC will support the evaluation of the Digital Automatic Couplers (DAC) tested in the Swedish demo trains, as well as the evaluation of braking strategies with a focus on Electro-Pneumatic (EP) braking enabled by DAC. In WP22, Functional Requirements and Concepts of Innovative Freight Assets, CHARMEC will work on developing powertrain specifications for self-propelled freight wagons for different use cases. In WP29, Standardised European Railway Checkpoints at Borders and Other Operational Stop Points, CHARMEC will develop proposals for alarm limits for dynamic wheel loads caused by wheel damage.

Klara Mattsson, Jens Nielsen, Lars Fehrlund, Michele Maglio and Tore Vernersson: On wayside detector measurement of wheel–rail impact loads induced by wheel flats – Data analysis, alarm levels and regulations, *Proceedings Sixth International Conference on Railway Technology (Railways 2024)*, Prague (Czech Republic) September 2024, 14 pp (also listed under project SP37) doi:10.4203/ccc.7.7.10

David Krüger, Mathilde Laporte, Jonan Morales, Iñigo Adin, Björn Pålsson, Behzad Kordnejad and Ingrid Nordmark: Preliminary concepts and specifications for a self-propelled wagon, *Proceedings 6th SmartRaCon Scientific Seminar (SRC6SS)*, San Sebastian (Spain) October 2024, 9 pp ceit.es/documents/24233193/41324655/SRC6SS_Proceedings_2024.pdf

EU26. FUTURE

FUTURE – Delivering Innovative Rail Services to Revitalise Capillary Lines and Regional Rail Services

Project leader	Docent Tore Vernersson, Mechanics and Maritime Sciences / Division of Dynamics
Period	2024-01-01 – 2024-06-30 (– 2026-11-30)
Budget Trafikverket / EU	Stage 10: kSEK 80 Stage 11: kSEK 667
Budget Chalmers	Stage 10: kSEK 4 Stage 11: kSEK 49

In FUTURE, the overall objectives are to ensure the long-term viability of regional railways by reducing the total cost of ownership (TCO), while ensuring high service quality and operational reliability. The project aims to increase customer satisfaction and make rail an attractive and preferred mode of transport. These goals are to be achieved through a concept tailored to regional railways but transferable across Europe, encompassing digitalisation, automation and the use of common and new technologies for control command and signalling, wayside components, rolling stock, and customer information. Of the 12 Work Packages in FUTURE, CHARMEC researchers are active in WP5/10, Regional Rail Rolling Stock, and will support with brake system requirements and development.

EU27. IAM4RAIL – High Speed Turnouts

IAM4RAIL – Condition Monitoring for High-Speed Turnouts

Project leader	Docent Björn Pålsson, Mechanics and Maritime Sciences / Division of Dynamics
Period	2024-01-01 – 2024-06-30 (– 2026-11-30)
Budget EU	Stage 10: kSEK 910 Stage 11: kSEK 1 084
Budget Chalmers	Stage 10: kSEK 14 Stage 11: kSEK 192 + 890

In IAM4RAIL, in collaboration with voestalpine, CHARMEC is active in WP10/11, Multisource/Multipurpose Intelligent Asset Management System (IAMS) Application. CHARMEC's work concerns the development of condition monitoring systems for high-speed turnouts, with an emphasis on detecting rail cracks and running surface damage. voestalpine Railway Systems has instrumented a high-speed turnout in Spain, which will serve as a reference case and testbed for the project.

SP32. SUSTAINABLE RAILWAY ASSET MANAGEMENT

Hållbar förvaltning av järnvägar

Project leader	Professor Anders Ekberg, Mechanics and Maritime Sciences / Division of Dynamics
Co-workers	Docent Astrid Pieringer, Architecture and Civil Engineering, Professor Magnus Ekh, Industrial and Materials Science, Professor Elena Kabo, Mechanics and Maritime Sciences, Professor Jens Nielsen, Mechanics and Maritime Sciences, Professor Johan Ahlström, Industrial and Materials Science
Period	2021-01-01 – 2021-12-31
Budget	Cash from Chalmers Area of Advance Transport KSEK 290 for Stage 9 and KSEK 290 for Stage 10 (counted as in-kind contributions to CHARMEC)

Railways typically have a fleet where vehicles are operating for decades. The life cycle cost and environmental footprint are closely related to how these vehicles are managed during their operational life. In particular, it is essential to perform cost-efficient maintenance that minimises the risk for traffic disruptions, such as those caused by failures. This activity is generally referred to as asset management and involves a multitude of aspects. This study was focused on technical and environmental aspects in strategic areas, specifically the structural behaviour of trains and track, the deterioration of mechanical components, noise and vibration, and energy consumption. The research set out from key governing parameters and means of measuring these, aiming to employ operational data for decisions on investments and maintenance. This included estimating uncertainties and how improved use of operational data and predictive models would influence the level of uncertainty.

For wheels and rails, the key parameters, measurable parameters, and links between these were investigated. Possibilities for predicting deterioration, and thereby related maintenance needs, were identified. The results are reported in a scientific paper, see below.

Uncertainties in deterioration and maintenance predictions related to grinding, milling, and increases in operational loading were investigated. This work was correlated with our research in project EU21. A report on surface re-profiling needs, methods, and challenges was prepared and is reported under project EU21. Pilot studies on the consequences of increased axle load on wheel and rail deterioration were conducted, with results reported under projects MU22 and EU21. A link to risk analyses was established in co-operation with project SP33.

A compendium on asset management in the rail sector, with a focus on the use of ISO 55000 and risk analysis, was authored within the project and used in the course Railway Technology (MMS 180) within the Master's programme in Mobility Engineering at Chalmers.

Anders Ekberg, Elena Kabo and Roger Lundén: Rail and wheel health management, *Wear*, vol 526–527, 2023, 10 pp (revised article from conference *CM2022*. Also listed under project MU22) doi.org/10.1016/j.wear.2023.204891

Anders Ekberg and Elena Kabo: Asset management – A brief introduction with focus on the ISO 55000 standard and mechanical deterioration of railway related assets, Research Report 2022:04, *Chalmers Mechanics and Maritime Sciences/ CHARMEC*, Gothenburg 2024, 21 pp (also listed under project MU22)

Derailment of the last two coaches in a Swedish passenger train on 6 July 1997 between Lästringe and Tystberga on a regional line south of Stockholm and north of Nyköping. The day was calm with few clouds and a maximum temperature of about 25 °C. According to eyewitnesses, the lateral buckling and displacement of the track gradually increased as the train braked

SP33. MORE ROBUST SWITCHES THROUGH IMPROVED CONTROL OF THE SWITCH RAIL

Robustare spårväxlar genom förbättrad tungkontroll

Project leader	Professor Anders Ekberg, Mechanics and Maritime Sciences / Division of Dynamics
Co-workers	Professor Elena Kabo, Dr h c Björn Paulsson and Docent Björn Pålsson, Mechanics and Maritime Sciences
Period	2021-01-01 – 2021-12-31
Budget Chalmers	Stage 9: kSEK 420 Stage 10: kSEK 260

The project was financed by Trafikverket (through CHARMEC's budget)


TKKs (indicated by yellow ovals) in a Swedish switch. Photo: Björn Paulsson

The aim of this project was to enhance understanding of the consequences of foreign objects becoming trapped between the switch rail and the stock rail. To aid in detecting these objects, switch rail contact sensors known as TKK have been used in Sweden since 1987. This unique Swedish solution currently has approximately 12 500 sensors in track. However, alarms (often incorrect) from these sensors are a significant cause of current traffic disruptions. The project included a limited feasibility study to determine whether, and to some extent how, it is possible to reduce the number of TKKs while maintaining the safety level.

From a practical perspective, the aim was to enhance knowledge about risk levels to significantly reduce disruptions. More specifically, this relates to the risk that an object capable of causing a derailment becomes trapped between the switch rail and the stock rail, while at the same time the driving and locking device indicates that the switch rail is in the correct position and the signalling system displays a "green light".

The project showed that several parameters, such as the deformation of a trapped ballast stone and the torsional rigidity of the switch rail, should be included in the analyses. For example, static load analyses using ABAQUS revealed that the switch rail is torsionally weak and not as stiff as previously assumed. Additionally, it was confirmed that realistic simulations of wheel–switch rail interaction can be conducted using the SIMPACK code.

The project was discussed in meetings with Trafikverket and Transportstyrelsen. A final report was reviewed and published, see below. The results were communicated to Trafikverket and the participating partners.

Sucheth Bysani was recruited as a PhD student in the parallel doctoral project TS24, which continues the work from project SP33.

Björn Paulsson and Anders Ekberg: More robust switches through improved control of the switch rail, Research Report 2022:01, *Chalmers Mechanics and Maritime Sciences*, Gothenburg 2022, 48 pp, research.chalmers.se/en/publication/530774


Tread brake testing at the Railway Technical Research Institute (RTRI) in Tokyo, Japan, in the collaborative experimental work between CHARMEC and RTRI, see project SD11. The test rig is equipped with a Lucchini wheel and Japanese composite brake blocks

SP34. FULL-SCALE BRAKE TEST RIG

Fullskalig provrigg för bromsar

Project leader	Docent Tore Vernersson, Mechanics and Maritime Sciences / Division of Dynamics
Co-workers	Professor Roger Lundén, Research Engineer Jan Möller and Mr Eric Voortman Landström, MSc, Mechanics and Maritime Sciences
Period	2020-02-01 – 2024-06-30
Chalmers budget (excluding university basic resources)	Stage 9: ksek 600 Stage 10: ksek 1 500 + 100 (+ 1 900 in S2R)
Industrial interests in-kind budget	Stage 9: ksek 0 + 0 Stage 10: ksek 200 + 200 *(Lucchini Sweden + Wabtec)*

A versatile full-scale brake test rig has been designed and constructed at Chalmers to support CHARMEC's work in acquiring comprehensive knowledge of tread brakes and establishing limits for their commercial applications, considering the requirements of today and the near future. The primary focus is on the sliding contact between the wheel and brake block, and the rolling contact between the wheel and rail. During the design of the testing facility, emphasis has been placed on achieving compact dimensions and wide-range usability in frictional brake testing, encompassing freight wagons, metros, and commuter trains. Additionally, the facility is intended to be functional for future research on disc brakes.

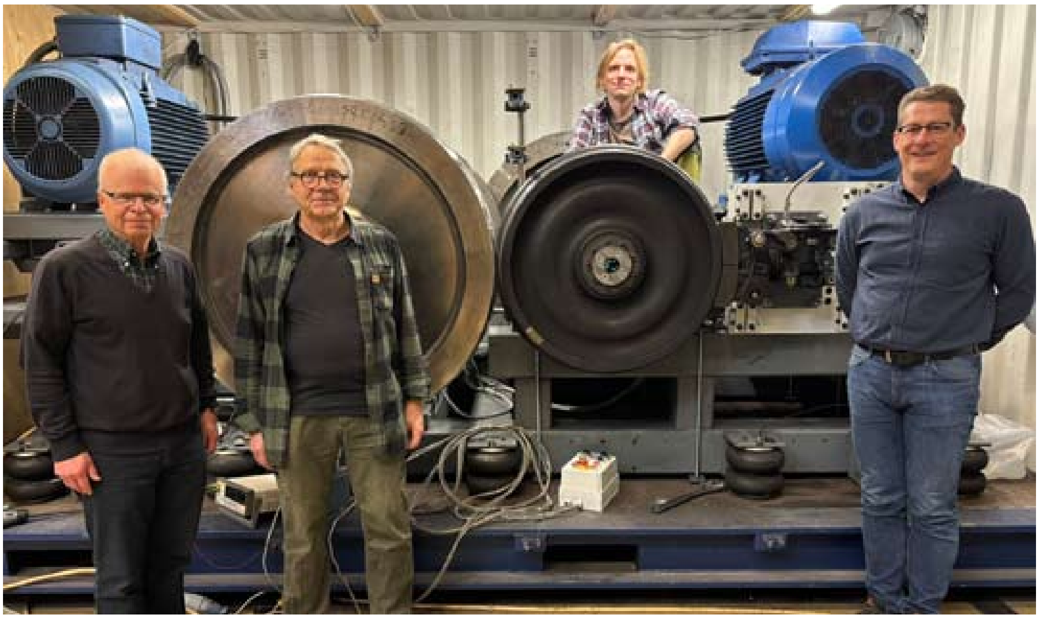
The brake rig is equipped with two electric motors that can be used either jointly, powering the block-braked wheel during simulated drag braking and stop braking, or separately, powering the block-braked wheel and a so-called rail-wheel to generate a frictional force at their rolling contact. The functionality is enhanced by the ability to manipulate the support of the rail-wheel unit to control the lateral wheel–rail contact position and the attack angle of the rail-wheel. The brake rig is situated in a laboratory hall at Chalmers University of Technology.

Results from tests using the brake rig have been instrumental for the work in project SD11. In particular, experimental results were essential for the calibration of numerical models of global wheel behaviour at extreme temperatures and for investigating the influence of temperature on rolling contact fatigue (RCF) life. An initial finding, using our high-frequency, high-resolution thermographic camera, revealed the presence of globally unevenly distributed temperatures during braking, which is significant for assessing wheel integrity, see project SD11. This discovery propelled the development of a brake-actuator-flexibility device for use at general tread braking, and especially for tests involving the rail-wheel to prevent the development of out-of-round wheels during braking.

The full-scale brake test rig is available for collaborative research and industrial projects in the fields of thermomechanical behaviour, RCF, wear, particle emissions, and other phenomena for which the brake test rig could be modified to facilitate.

The project has received specific funding from an additional subproject of In2Track3, see under project EU21. The main parts of the brake rig were completed within project SP34. However, the rig is continuously being further developed within projects SD11 and SD12.

For the joint reference group, see under project SD11.



From left: Roger Lundén, Jan Möller, Eric Voortman Landström and Tore Vernersson at the brake rig. Photo taken in 2025

SP35. INTEGRATED TRACK DESIGN FOR REDUCED NOISE EFFECTS

Integrerad spårdesign för minskade bullereffekter

Project leader	Docent Astrid Pieringer, Architecture and Civil Engineering / Division of Applied Acoustics
Co-workers	Dr Jannik Theyssen, Architecture and Civil Engineering, Professor Roland Sottek, Architecture and Civil Engineering, and Professor Jens Nielsen, Mechanics and Maritime Sciences
Period	2023-01-01 – 2024-06-30 (– 2025-12-31)
Budget Chalmers	Cash from Chalmers Area of Advance Transport KSEK 2025 for Stage 10 and KSEK 675 for Stage 11 (counted as in-kind contributions to CHARMEC)

Noise and vibration exposure can cause stress, sleep disturbance, and reduced cognitive performance, leading to severe health effects. Hence, railway noise and vibration often hinder the expansion of rail capacity in Europe, limiting the shift towards a greener, more climate-friendly mode of transport. Improved track design may be a cost-effective measure to reduce rolling and impact noise (e g, from crossings), but it requires an integrated approach that considers both acoustic and mechanical performance due to partly conflicting demands. For example, rail noise can be reduced by implementing rail pads with higher stiffness. However, stiffer rail pads also result in higher mechanical loads and increased levels of sleeper vibration. As the impact of noise on health and wellbeing is strongly dependent on human perception, it is essential to consider not only the strength of sound but also its frequency content and time structure. Therefore, this project addresses integrated acoustic and mechanical track design based on perception-based noise evaluation.

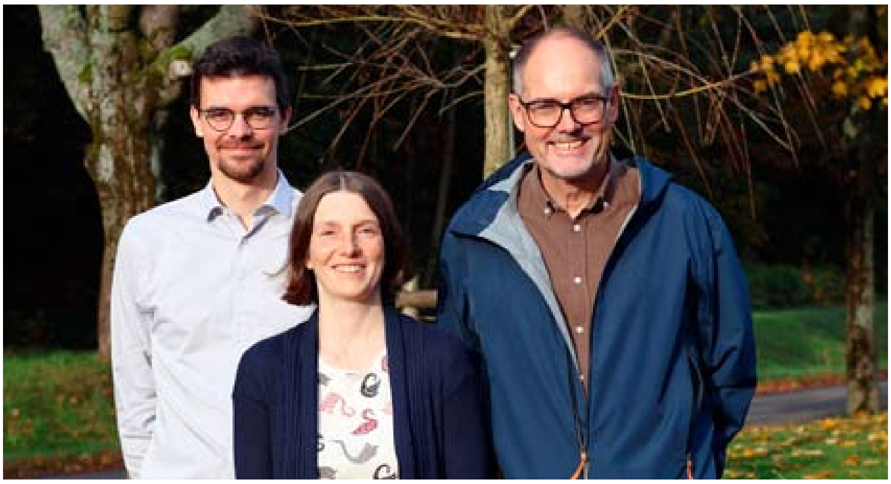
In SP35, two dynamic models developed within CHARMEC, DIFF and WERAN, have been used to predict vibration signals in the rail due to roughness excitation in the rolling contact. A method developed in SP35 enables the efficient prediction of pass-by sound pressure signals on the track side based on these vibration signals. In this method, acoustic transfer functions predicted using a Wavenumber-domain Boundary Element method (WBE) are transformed to find the sound radiated by sections of railway track, facilitating an efficient prediction of sound pressure signals. The developed method was employed to predict the pass-by pressure radiated by track vibration in DIFF and WERAN for various pass-by scenarios, including a single wheel at different speeds, multiple passing wheels, and transient effects induced by a wheel flat. A good agreement was found between the sound pressure signals evaluated in DIFF and WERAN. A parametric study investigated the necessary spatial length and discretisation of the track model. The method shows promising potential for perception-based noise evaluation of railway noise.

Jannik Theyssen, Astrid Pieringer and Wolfgang Kropp: A time-domain model for railway rolling noise. *Proceedings Fortschritte der Akustik – DAGA 2023*, 49. Jahrestagung für Akustik, Hamburg (Germany) March 2023, pp 1015–1018
pub.dega-akustik.de/DAGA_2023/data/articles/000632.pdf

Jannik Theyssen and Astrid Pieringer: Towards auralization of pass-by noise from railway wheels – Sensitivity to the lateral contact position, *Proceedings 10th Convention of the European Acoustical Association – Forum Acusticum*, Turin (Italy) September 2023, pp 5621–5628
https://dael.euracoustics.org/confs/fa2023/data/articles/000315.pdf

Jannik Theyssen: The radiation from railway wheel modes and their effect on loudness, sharpness, and equivalent pressure level, *Acta Acustica*, vol 8, 2024, 10 pp
doi.org/10.1051/aacus/2024012

Jannik Theyssen, Jens Nielsen and Astrid Pieringer: A time-domain approach to predict sound radiation from track vibrations, *Proceedings Internoise 2024*, Nantes (France) August 2024, 8 pp



From left: Dr Jannik Theyssen, Docent Astrid Pieringer and Professor Jens Nielsen in project SP35

SP36. SINGLE SENSOR CONDITION MONITORNG FOR NOISE AND DETERIORATION OF RAILWAY CROSSINGS

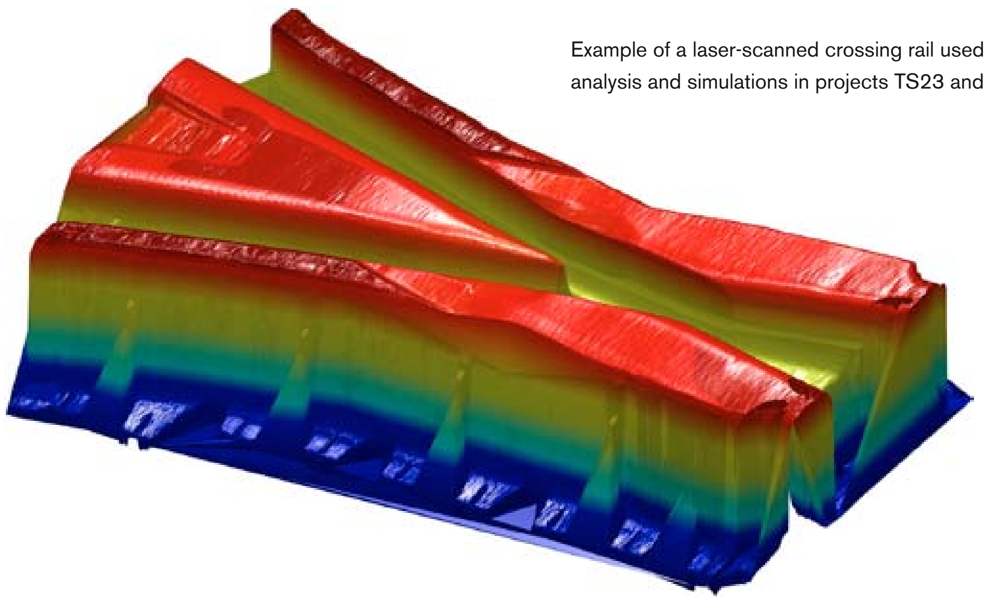
Tillståndsövervakning av buller och nedbrytning i järnvägskorsningar med en sensor

Project leader	Docent Björn Pålsson, Mechanics and Maritime Sciences / Division of Dynamics
Co-workers	Professor Magnus Ekh, Industrial and Materials Science
Period	2023-01-01 – 2024-06-30 (– 2024-12-31)
Chalmers budget	Cash from Chalmers Area of Advance Transport KSEK 450 for Stage 10 and KSEK 150 for Stage 11 (counted as in-kind contributions to CHARMEC)

This project was initially intended to focus on the condition monitoring of indirect noise emissions from crossings by measuring them indirectly via structural vibrations.
This was to be achieved using the same accelerometer instrumentation already designed for monitoring track deterioration, see project TS21. However, it was soon concluded that the idea of continuous monitoring of noise emissions from individual crossings is not particularly relevant, as it is unlikely that noise levels would be severe enough to motivate crossing maintenance. Instead, the need for maintenance would rather be determined by the mechanical deterioration of crossings, already predicted through the post-processing of existing sensor data. Consequently, the project shifted focus to two developments aimed at the broader goal of Digital Twins for Switches & Crossings (S&C), a computationally efficient plasticity model to predict the deterioration of the running surface in crossings, and condition monitoring solutions based on inertia (acceleration) measurements to identify ballast conditions and running surface irregularities in S&C.

One approach to speeding up cyclic plasticity simulations for railway applications is to replace a time-domain material model with a cycle-domain model. Preliminary work has been carried out to formulate such a cycle-domain model using machine learning and neural networks, with training data derived from a cycle plasticity (time-domain) model. Additionally, the symbolic regression technique was used as a model discovery tool to formulate a so-called interpretable model. These developments are intended to be used, refined, and applied to railway applications in project MU41.

For condition monitoring, a literature study has been conducted to benchmark methods for displacement reconstruction, inverse load identification, and condition monitoring in general. The most promising methods identified were Kalman filter-based approaches and purely data-driven methods for signal classification and anomaly detection. A dual Kalman filter for the identification of displacements and forces from measured accelerations has been implemented for evaluation. The results are promising, although not yet superior to the methods from project TS21, and further developments will continue in project EU27. Additionally, a multi-body simulation model of a high-speed turnout has been developed to better understand the dynamic response of swing nose crossings during train passages.
The condition monitoring part of the project has been conducted in collaboration with project EU27.



Example of a laser-scanned crossing rail used for analysis and simulations in projects TS23 and TS25

SP37. IMPROVED REGULATIONS AND PROCEDURES FOR DAMAGED WHEELS

Förbättrade regler och rutiner för skadade hjul

Project leader	Professor Elena Kabo, Mechanics and Maritime Sciences / Division of Dynamics
Co-workers	Dr Michele Maglio, Trafikverket, Mr Lars Fehrlund, Green Cargo, Mr Pär Söderström, SJ, Professor Anders Ekberg, Professor Jens Nielsen and Docent Tore Vernersson, Mechanics and Maritime Sciences
Period	2023-07-01 – 2024-06-30 (– 2026-06-30)
Budget Chalmers	Stage 10: kSEK 519 Stage 11: kSEK 1 355
Industrial interests in-kind budget	Stage 10: kSEK 0 + 0 + 0 + 0 Stage 11: kSEK 50 + 100 + 22 + 100 (Green Cargo + Lucchini + SweMaint + Wabtec)

The project is financed by VINNOVA and Trafikverket (through CHARMEC's budget)

To successfully increase passenger and freight traffic, railway transportation needs to be safe, reliable, environmentally friendly, cost-efficient, and on time. To achieve this, the aims of this project are to improve regulations and procedures to avoid traffic disruptions caused by infrastructure failures and unnecessary stopping of trains. This will provide better means to plan track maintenance actions based on traffic conditions and promote increased collaboration and understanding between the infrastructure owner and rolling stock operators.

The basis for the improved regulations and procedures involves innovative means of relating wheel loads to the risk of failure and their influence on deterioration. Regulations and procedures for wheel removal will be grounded in objective measured quantities, thereby eliminating potential human errors, establishing a scientific foundation for legal requirements, and enabling a new level of automation in maintenance planning. To achieve the required level of accuracy in relating wheel loads to their consequences, the project employs extensive research, predictive models, and full-scale tests carried out by the involved parties. This will build a level of confidence that allows wheel removal regulations to be designed based solely on automated load measurements.

The partners in the project represent the Swedish freight operator Green Cargo, the Swedish passenger train operator SJ, and the Swedish Transport Administration Trafikverket.

Jens Nielsen, Anders Ekberg and Tore Vernersson: Placement of wheel impact load detectors, In2Track3, Deliverable 3.4 Wheel/rail interaction, simulations and track monitoring, Appendix: Added work in accordance with amendments, 2024, 6 pp (also listed under project EU21)

Jens Nielsen, Klara Mattsson, Anders Ekberg, Elena Kabo, Tore Vernersson, Matthias Asplund, Lars Fehrlund and Pär Söderström: Improved rules and regulations of damaged wheels, *Proceedings 22nd Nordic Seminar on Railway Technology*, Stockholm June 2024 (Summary and PowerPoint presentation)

Anders Ekberg and Elena Kabo: Estimating residual risks for rail breaks, *ibidem*, Stockholm (Sweden), June 2024 (Summary and PowerPoint presentation. Also listed under project MU22)

Klara Mattsson, Jens Nielsen, Lars Fehrlund, Michele Maglio and Tore Vernersson: On wayside detector measurement of wheel–rail impact loads induced by wheel flats – Data analysis, alarm levels and regulations, *Proceedings Sixth International Conference on Railway Technology (Railways 2024)*, Prague (Czech Republic) September 2024, 14 pp (also listed under project EU25) doi:10.4203/ccc.7.7.10

Jens Nielsen, Lars Fehrlund, Michele Maglio, Pär Söderström, Anders Ekberg, Elena Kabo and Tore Vernersson: Towards improved regulations and procedures for damaged wheels – Assessment of wheel impact load detectors, *Chalmers Mechanics and Maritime Sciences*, Research Report 2024:04, 2024, 72 pp

Example of a wheel impact load detector (left photo by Matthias Asplund, Trafikverket) used for identifying damaged (out-of-round) wheels (see example on the right), which may cause detrimental loading of the track, infrastructure failures, and traffic disruptions

SP38. REDUCED MATERIAL CONSUMPTION IN RAILWAY OPERATIONS

Reducerad materialförbrukning inom järnvägsdrift

Project leader	Professor Elena Kabo, Mechanics and Maritime Sciences / Division of Dynamics
Co-workers	Professor Johan Ahlström, Industrial and Materials Science, and Professor Anders Ekberg, Mechanics and Maritime Sciences
Period	2024-01-01 – 2024-06-30 (– 2024-12-31)
Chalmers budget	Cash from Chalmers Area of Advance Transport kSEK 300 for Stage 10 and kSEK 300 for Stage 11 (counted as in-kind contributions to CHARMEC)

Material consumption in railway operations is significant, with tens of thousands of tonnes of steel being worn, machined off, or scrapped every year. This relates to some 15 600 km of track and around 25 000 wheelsets operating daily on Swedish railways. This constitutes one of the major remaining environmental burdens of railway operation, impacting both resources (via mining and steelmaking) and energy (re-melting and transport). Reducing material consumption in the railway sector through enhanced design, reduced wear, and improved maintenance strategies was the core objective of the present project. Here, extensive knowledge of material deterioration, the potential for continuous monitoring, and the use of numerical simulations, predictions, and big data analyses were investigated. This included examining how altered practices would affect safety and economy. An important aspect is how current regulations can and should be adapted to accommodate these "new" technologies.

A study was conducted on the influence of axle load on material deterioration rates. The influence of increased vertical loads on surface crack initiation on the railhead was found to be small. However, an increase in axle load from 30 to 32.5 tonnes also increases lateral load, which promotes crack formation and reduces the lifespan of wheels and rails in curves by approximately 30%.

Following a derailment on the Iron Ore Line in December 2023, investigations were conducted to improve wheel design and maintenance. The aim was to prevent similar accidents, which necessitated the replacement of approximately 40 km of rail, 30 000 sleepers and large quantities of ballast, etc. Note that overly conservative requirements could lead to the premature scrapping of wheels, each containing around 300 kg of steel.

Simulation models of wheel and rail material deterioration have been enhanced and employed in the analyses mentioned above. These calibrated models are a prerequisite for optimising material use while preventing accidents.

Extreme material damage of a freight wheel occured following an event of locked tread brakes, resulting in very high temperatures and hot rolling of the wheel rim from wheel-rail contact

ACADEMIC AWARDS

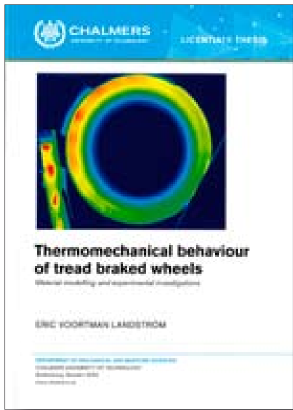
(up to June 2024)

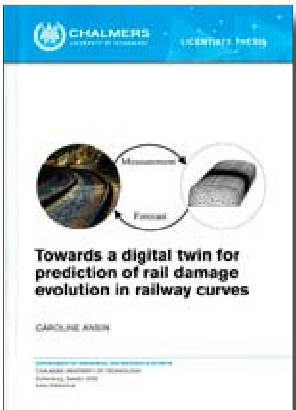
Research in railway mechanics at Chalmers University of Technology has resulted in the conferring of the higher academic degrees listed below

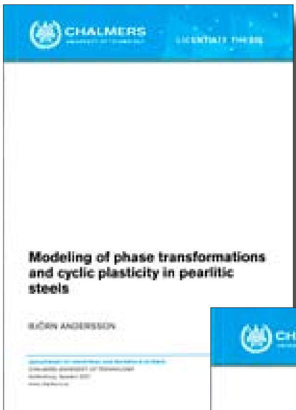
Licentiate of Engineering (Lic Eng)

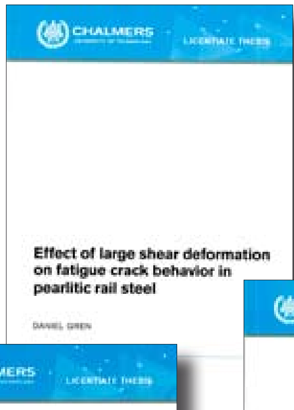
Jens Nielsen	1991-02-19
Mikael Fermér	1991-04-09
Åsa Fenander	1994-09-09
Annika Igeland	1994-10-06
Johan Jergéus	1994-11-22
Anders Ekberg	1997-02-18
Tore Vernersson	1997-09-29
Johan Jonsson	1998-05-13
Johan Ahlström	1998-12-11
Lars Jacobsson	1999-01-28
Johan Oscarsson	1999-03-12
Martin Petersson	1999-10-12
Rikard Gustavson	2000-05-11
Clas Andersson	2000-11-17
Torbjörn Ekevid	2000-12-19
Daniel Thuresson	2001-05-16
Carl Fredrik Hartung	2002-11-22
Lars Nordström	2003-01-24
Simon Niederhauser	2003-02-28
Anders Johansson	2003-09-05
Per Heintz	2003-12-03
Göran Johansson	2004-06-03
Per Sjövall	2004-10-01
Anders Karlström	2004-10-21
Elias Kassa	2004-12-16
Eka Lansler	2005-01-12
Anders Bergkvist	2005-06-09
Håkan Lane	2005-06-10
Niklas Köppen	2006-11-10
Johanna Lilja	2006-11-23
Johan Tillberg	2008-06-04
Johan Sandström	2008-10-14
Astrid Pieringer	2008-12-02
Jessica Fagerlund	2009-06-08
Peter Torstensson	2009-11-27
Krste Cvetkovski	2010-04-23
Jim Brouzoulis	2010-05-07
Hamed Ronasi	2010-09-24
Albin Johnsson	2011-02-24
Björn Pålsson	2011-04-14
Martin Schilke	2011-06-08
Sara Caprioli	2011-12-20
Andreas Draganis	2011-12-21
Shahab Teimourimanesh	2012-02-23
Nasim Larijani	2012-05-24
Kalle Karttunen	2013-01-17
Emil Gustavsson	2013-03-22
Sadegh Rahrovani	2014-02-27
Milad Mousavi	2014-06-05
Xin Li	2014-11-25
Ivan Zenzerovic	2014-12-02
Robin Andersson	2015-06-04
Dimitrios Nikas	2016-06-10
Dimosthenis Floros	2016-11-25
Ali Esmaeili	2016-12-16
Casey Jessop	2017-03-03
Mandeep Singh Walia	2017-03-20
Knut Andreas Meyer	2017-10-06
Emil Aggestam	2018-05-25
Rostyslav Skrypnyk	2018-06-07
Jannik Theyssen	2020-06-09
Michele Maglio	2020-10-09
Marko Milosevic	2021-06-04
Björn Andersson	2021-12-20
Mohammad Salahi Nezhad	2022-03-31
Daniel Gren	2022-08-30
Erika Steyn	2022-10-28
Eric Voortman Landström	2022-11-22
Kourosh Nasrollahi	2023-04-12
Caroline Ansin	2023-06-05

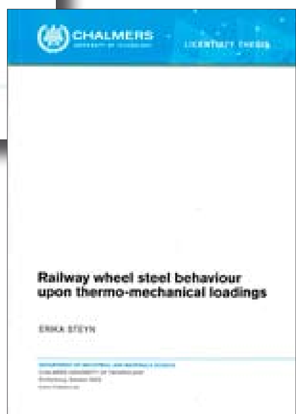
Licentiate theses submitted by CHARMEC researchers during Stage 10

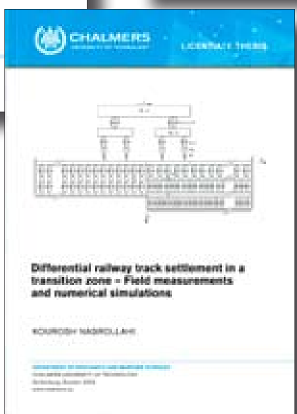


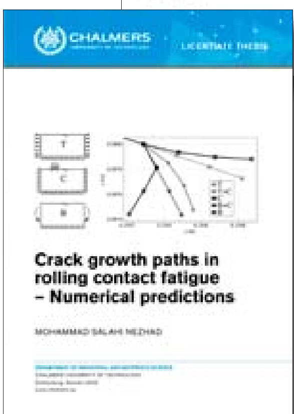






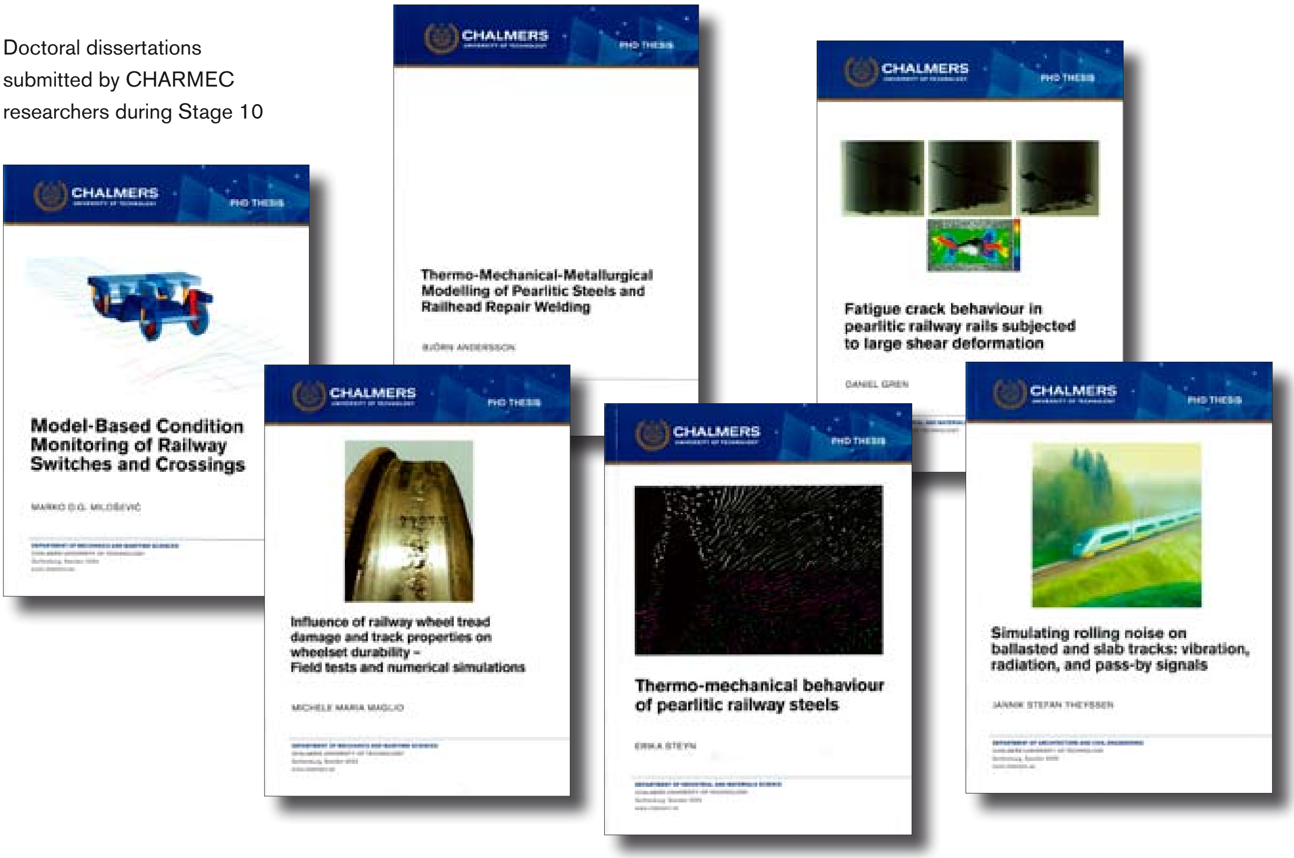






ACADEMIC AWARDS (cont'd)

Doctoral dissertations submitted by CHARMEC researchers during Stage 10



Doctor of Engineering (PhD)

Jens Nielsen	1993-12-16
Mikael Fermér	1993-12-17
Annika Igeland	1997-01-24
Åsa Fenander	1997-05-23
Johan Jergéus	1998-01-30
Anders Ekberg	2000-04-07
Johan Jonsson	2000-06-09
Jonas Ringsberg	2000-09-15
Johan Ahlström	2001-03-02
Johan Oscarsson	2001-04-20
Rikard Gustavson	2002-11-07
Torbjörn Ekevid	2002-12-18
Clas Andersson	2003-06-04
Anders Skyttebol	2004-09-10
Roger Johansson	2005-06-08
Anders Johansson	2005-09-23
Lars Nordström	2005-11-10
Simon Niederhauser	2005-12-09
Tore Vernersson	2006-06-08
Per Heintz	2006-09-28
Göran Johansson	2006-09-29
Daniel Thuresson	2006-10-06
Anders Karlström	2006-10-13
Håkan Lane	2007-05-25
Elias Kassa	2007-10-19
Per Sjövall	2007-11-09
Johan Tillberg	2010-12-10
Astrid Pieringer	2011-05-20
Johan Sandström	2011-11-14
Hamed Ronasi	2012-03-29
Jim Brouzoulis	2012-10-05
Krste Cvetkovski	2012-10-16
Peter Torstensson	2012-11-02
Martin Schilke	2013-03-15
Björn Pålsson	2014-02-28
Shahab Teimourimanesh	2014-03-07
Nasim Larijani	2014-06-10
Andreas Draganis	2014-09-03
Sara Caprioli	2015-01-15
Emil Gustavsson	2015-05-29
Kalle Karttunen	2015-06-11
Sadegh Rahrovani	2016-03-18
Milad Mousavi	2016-09-30
Ivan Zenzerovic	2018-01-19
Robin Andersson	2018-06-08
Dimitrios Nikas	2018-10-18
Ali Esmaeili	2019-01-10
Dimosthenis Floros	2019-01-18
Casey Jessop	2019-06-13
Xin Li	2019-09-26
Knut Andreas Meyer	2019-10-04
Mandeep Singh Walia	2019-11-20
Rostyslav Skrypnyk	2020-06-05
Emil Aggestam	2021-06-11
Jannik Theyssen	2022-12-15
Michele Maglio	2023-01-27
Björn Andersson	2024-03-27
Marko Milosevic	2024-05-24
Erika Steyn	2024-06-05
Daniel Gren	2024-06-14

Docent (highest academic qualification in Sweden)

Roger Lundén	1993-03-23
Jens Nielsen	2000-11-09
Jonas Ringsberg	2004-04-02
Anders Ekberg	2005-08-26
Elena Kabo	2008-12-15
Johan Ahlström	2010-03-08
Tore Vernersson	2016-09-20
Peter Torstensson	2021-05-18
Björn Pålsson	2021-06-18
Astrid Pieringer	2023-09-08

Research Professors

Elena Kabo	2017-09-01
Jens Nielsen	2018-01-01

The status report that follows applies as of December 2024. The first year of each partner's involvement with CHARMEC is indicated (and before that, by bilateral agreement with the railway mechanics group at Chalmers Solid Mechanics).

Alstom Transportation Germany GmbH (2000)
Leading societies towards a low-carbon future, Alstom develops and markets mobility solutions that provide a sustainable foundation for the future of transportation. Alstom's product portfolio ranges from high-speed trains, metros, monorail, and trams to integrated systems, customised services, infrastructure, signalling, and digital mobility solutions. With Bombardier Transportation joining Alstom on 29 January 2021, the group's turnover exceeded EUR 17 billion for the 12-month period ending on 31 March 2024. The group has its headquarters in Paris, is listed on Paris Stock Exchange, and is a part of the CAC 40 index. Alstom has approximately 84 000 employees from 184 nationalities and has a presence in 64 countries. To develop and support its products and solutions, Alstom employs around 24 000 engineers. A key focus area concerns CHARMEC's activities assessing the effects of wheel–rail interaction on contact mechanics, ride dynamics, wheel wear, wheel damage mechanisms, rail wear, rail damage and noise generation. Other notable areas of interest in the co-operation with CHARMEC include wheelset component material technology, as well as braking system friction pairs and their performance.

Green Cargo AB (2000)
Green Cargo is a state-owned Swedish rail logistics company headquartered in Stockholm/Solna, employing approximately 1 750 personnel across Sweden. The company operates a fleet of around 350 locomotives and 4 750 freight wagons, collectively covering approximately 9.7 billion net tonne-kilometres annually. The Green Cargo network encompasses roughly 200 domestic terminals and is connected to several international routes across Europe. Notably, nearly 98 percent of the company's total transport work is powered by electric locomotives, using electricity sourced entirely from fossil-free energy. On an average weekday, Green Cargo transports 31 million net tonne-kilometres, effectively replacing around 9 000 heavy truck movements on the national road network, thereby contributing significantly to more sustainable freight transport. Key areas of collaboration with CHARMEC include research and development in braking performance, noise emissions, fatigue strength, and the optimisation of wheel and axle systems. This encompasses improvements in design, material selection, and maintenance strategies, all aimed at enhancing safety, reliability, and operational efficiency.

Heidelberg Materials Precast Abetong AB (1995 and 1988)
Heidelberg Materials Precast Abetong, whose head office is in Växjö, is part of the HeidelbergCement Group and manufactures prefabricated and pretensioned concrete structural components. About 500 people are employed in Sweden, where the annual turnover is slightly over MSEK 1 100. Areas of interest for Heidelberg include the design and manufacture of railway sleepers fitted with fastenings and pads for rails. Of particular interest in the co-operation with CHARMEC are tools for identifying loads on sleepers installed in tracks, for the structural analysis and design of sleepers for main lines and turnouts, and for predicting the amount of noise emitted by the sleepers. Due to the previously planned construction of high-speed tracks in Sweden, Heidelberg decided to expand its existing railway activities to include expertise in slab track systems. Consequently, the company initiated two slab track-oriented PhD projects at CHARMEC running during the period 2016 – 2021. Both Trafikverket and Heidelberg have benefitted from the results obtained, which have been employed in further research.

Lucchini Sweden AB (1995 and 1987)
Lucchini Sweden is a railway wheelset manufacturer based in Surahammar with more than 150 years in the business. The company is the only wheelset manufacturer in Scandinavia and is a wholly-owned subsidiary of Lucchini RS in Italy, one of the world's leading suppliers of wheels and wheelsets for trains. Areas of interest for Lucchini Sweden in the co-operation with CHARMEC include the design, manufacturing, mounting, running, braking, and maintenance of wheelsets. Of particular interest are new materials for wheels and axles, and noise emission from wheels. The main end users of the wheelsets are passenger and freight train operators in Sweden, Denmark, Finland and Norway. Other major customers include manufacturers of new rolling stock and maintenance providers.

SJ AB (2006)
SJ is a Swedish partner that offers train travel, both as an independent operator and in collaboration with others. SJ is one of Sweden's most sustainable brands and is helping Sweden achieve its climate goals. The 5 400 employees of the group in Sweden and Norway enable many people to

choose train travel as the most sustainable mode of transport for longer journeys. As the market-leading train operating company, SJ connects Sweden and Norway and serves as the gateway to Scandinavia's capitals. Every day, our passengers and co-workers meet on one of SJ's 1 500 departures from over 400 stations. SJ is a private limited company owned by the Swedish government and tasked with operating profitable public railway transport.

SweMaint AB (2006)

SweMaint, whose head office is in Gothenburg, is the leading private North European provider of maintenance services specifically for railway freight wagons. SweMaint operates from 12 locations in Sweden with a total of about 275 employees. The annual turnover is around MSEK 560, and the market share in Sweden is approximately 70 %. One of SweMaint's main business areas is the management and operation of a wheelset pool for freight wagons. More than 8 000 wagons with 18 800 wheelsets are connected to the pool, with an additional 3 100 in a turn-over stock, ready for use. Each year, 5 000 wheelsets are exchanged, and most of them are refurbished by our workshop. Areas of interest in the co-operation with CHARMEC include the general improvement of wheelset quality and the development of cost-effective preventive maintenance programmes.

SYSTRA Sverige AB
(1995 and 1992)

Finding innovative solutions for sustainable travel is SYSTRA's core business. The constant forward drive, development, strong team spirit and high competence have secured SYSTRA an obvious place in the industry, working with authorities, municipalities, as well as private companies. Through the acquisition of Dalco Elteknik in 2016, SYSTRA's history extends back to 1987, when Dalco Elteknik was founded. Since its inception, SYSTRA has carried out numerous assignments within transport infrastructure in Sweden. Today, SYSTRA has 700 employees in Sweden, spread over 21 offices. We work on projects at all stages, from early investigations to the finished facility.

The Swedish vehicle business within SYSTRA originates from the Swedish state railway SJ and was incorporated almost 25 years ago when the consulting business was started. With all that experience and recent years of development in a deregulated rail sector, we have a complete portfolio of services to advise operators, maintenance contractors, vehicle owners, and traffic managers. Our core competences are vehicle technology and risk and safety work, which are required throughout the vehicles' entire lifespan. Our vision is to be a driving force for the development of digital strategic asset management for our Swedish rail vehicle fleet.

Trafikverket
(1995 and 1990)

Trafikverket (the Swedish Transport Administration) is responsible for the construction, operation, and maintenance of all state-owned roads and railways in Sweden. Trafikverket is also responsible for producing long-term plans for the transportation systems on roads and railways, at sea, and in the air. Trafikverket, whose head office is in Borlänge, has around 11 100 employees. Trafikverket's areas of interest in the co-operation with CHARMEC include the design, construction, and maintenance of all types of track structures, with a focus on high availability and reliability. Of particular interest are wear and corrugation of the railhead (requiring maintenance grinding) and the overall degradation of the track structure. It is particularly important to understand and predict the effects on the track of proposed higher train speeds and increased axle loads. Other important research areas are vibration, noise, and safety.

voestalpine Railway Systems GmbH (2002)

With over 160 years of experience, voestalpine Railway Systems is a global leader in railway infrastructure solutions. A subsidiary of voestalpine AG, the company specialises in providing high-quality rails, turnouts, signalling systems, and monitoring applications for all types of rail transport. Its comprehensive approach ensures that railway operators benefit from integrated and efficient solutions that enhance safety, reliability, and cost-effectiveness.

Employing around 7 000 people worldwide, voestalpine Railway Systems contributes significantly to modern mobility and transport networks. The company has played a key role in the digitalisation of railway systems by introducing advanced signalling and monitoring technologies. These innovations help increase network capacity, improve safety, and reduce maintenance costs by enabling predictive diagnostics and real-time infrastructure monitoring.

A distinguishing feature of voestalpine Railway Systems is its ability to provide fully integrated solutions tailored to different rail environments, including mixed traffic, urban transit, high-speed rail, and heavy-haul freight transport. By combining advanced materials with precise engineering, the company develops durable and efficient track components designed for long-term performance.

Rather than focusing solely on individual products, voestalpine Railway Systems takes a system-based approach to infrastructure management. Its solutions are designed to optimise the interaction between tracks, signalling, and rolling stock, helping railway operators achieve greater operational efficiency and lower life cycle costs. As rail transport continues to evolve, voestalpine Railway Systems remains at the forefront of innovation, supporting the modernisation of railway networks worldwide. Its expertise in developing high-performance infrastructure solutions makes it a key partner for railway operators looking to improve the safety and efficiency of their networks.

Wabtec Faiveley Nordic AB (1997)

The Wabtec Corporation is a leading global provider of equipment, systems, digital solutions, and value-added services for the freight and transit rail sectors. Headquartered in Wilmerding in Pennsylvania (USA), and listed on the NYSE, Wabtec employs around 25 000 people, of whom 220 are located in the Nordic region, with Landskrona (Sweden) as their base. The production unit in Landskrona manufactures new tread brake units and undertakes service and overhaul of the various Wabtec products used in the Nordic region. The main area of interest in the co-operation with CHARMEC is brake systems. The components for tread braking are being investigated, with particular focus on the interaction between brake block and wheel tread. New and optimised usage of tread brakes are sought, with emphasis on the simulation and reduction of wheel and block wear.

RESULTS AND EFFECTS IN INDUSTRY

In December 2024, Trafikverket and our partners in the Industrial Interests Group for Stage 9, Stage 10 and Stage 11 expressed the following views.

Alstom Transportation

During Stage 10, as well as in the previous CHARMEC stages, the wheelset research projects with a focus on rolling contact fatigue, contact mechanics, and damage mechanism development have been essential for the continued development of our understanding of the behaviour of railway wheels and their materials in service. Through our active involvement, we have been able to initiate or influence the development of new projects to build upon the knowledge gained from the previous projects and to address arising business needs. Alstom seeks to constantly improve the suitability, reliability, and performance of its mobility solutions. Therefore, CHARMEC's work in specialist areas such as wheel–rail contact mechanics, railway noise mechanisms, material technology, and friction pair behaviour remain key for this ongoing development cycle.

Green Cargo

The collaboration with CHARMEC has been highly valuable and instrumental in advancing Green Cargo's technical capabilities through joint investigations, analyses, and the development of innovative solutions. Within project SD10, the analysis of new brake discs for postal wagons resulted in a major design modification of the braking system, leading to the implementation of a new high-performance brake disc with improved operational characteristics. CHARMEC has also supported Green Cargo with critical crack propagation calculations, which were essential for establishing a safety-based maintenance schedule for a specific wheel axle type. Additionally, investigations into critical loading conditions on locomotive wheels enhanced understanding of crack initiation mechanisms in certain wheel designs, supporting both preventive maintenance and design improvements. A further area of collaboration involved the review of wheel load levels and wheel load detector systems. Knowledge gained, particularly from the investigation following a derailment on the Iron Ore Line, has strengthened Green Cargo's understanding of operational risks and informed safety strategies.

Leveraging CHARMEC's extensive research in wheel–rail interaction, a comprehensive calculation model was developed to assess the mechanical impact of operating heavy six-axle locomotives on Swedish infrastructure. This model enabled Green Cargo and Trafikverket to promptly evaluate associated risks and infrastructure wear, supporting sound operational and investment decisions. Moreover, CHARMEC continues to contribute to the development of composite brake blocks capable of enduring harsh winter conditions while minimising wheel wear.

Heidelberg Materials

CHARMEC has provided Heidelberg with an outstanding research environment. Of particular significance for the company is the employment, since 2003, of a PhD who trained for five years at CHARMEC, benefitting from its invaluable network and expertise in fields of major interest to Heidelberg. In the past, Heidelberg's role as a supplier of precast concrete sleeper technology had only moderate influence on the suppliers of other track components. Armed with a greater understanding of the interaction between sleepers and the rest of the track structure, communication with other suppliers has now improved. Heidelberg's participation in CHARMEC constantly provides us with better knowledge of the complex interaction between the full track structure and the running train. In the long run, this should lead to an overall optimisation of the track structure, using components in harmony rather than a cluster of sub-optimised components. Our improved understanding is also valuable when assessing new ideas presented within the business field of Heidelberg.

Lucchini Sweden

A significant achievement in the co-operation with CHARMEC has been the development of new passenger and freight wagon wheelsets for axle loads ranging from 20 to 32.5 tonnes, suitable for the Nordic climate. These wheelsets must fulfil stringent requirements to comply with various national and international standards. The brake test rig at the company's premises in Surahammar, see below, originally developed in collaboration with Chalmers but decommissioned a few years ago, has been very important in this work. The new full-scale brake test rig at Chalmers was established with support from Lucchini and is instrumental for ongoing and future development of railway wheels and brakes.

CHARMEC personnel have assisted Lucchini with technical developments and design calculations, improved workshop practices, documentation, and marketing of products. Previously, CHARMEC represented Lucchini Sweden on the CEN and ERWA committees. In recent years, there has been a collaboration between CHARMEC and Lucchini on education regarding wheel damage and research on condition-based maintenance through the SmartSet system, which measures stresses in the axle that can be used to estimate wheel–rail contact forces.

SJ

CHARMEC has provided support and expertise to SJ in several projects. A recent example is the joint project TS20, where installed measuring equipment on an SJ vehicle provided input to CHARMEC's model for evaluating the influence of wheel damage on wheel–rail contact forces. In addition, expert consultancy has been provided for investigations into the root causes of wheel cracks. Within the research areas of interest to SJ, CHARMEC's work is highly appreciated as it addresses the railway system from a comprehensive perspective. The centre plays an important role in bringing together people from industry, operators, infrastructure, and universities. SJ has also consulted with CHARMEC when assessing technical reports.

The brake test rig (inertia dynamometer) at Surahammar (used in projects SD1, SD4, EU1 and EU8) at its inauguration in 1989. From the left: Roger Lundén, Josef Rauch (from Sura Traction, now Lucchini Sweden), Bengt Åkesson, Elisabet Lundqvist and Lennart Nordhall (both from Sura Traction), Mikael Fermér (from Chalmers Solid Mechanics), and Nils Månsson and Sven A Eriksson (both from SJ Machine Division)

SweMaint

CHARMEC has provided SweMaint with an information hub and research environment, serving as a valuable partner for technical issues of importance to the company. CHARMEC has assisted with studies on how to improve the reliability of wheels and axles, and has engaged in discussions on technical improvements. For the future, we look forward to increasing our understanding of strategic maintenance programmes, in relation to both the wheelset and the wagon itself, with the aim of optimising the economic performance of the complete vehicle.

SYSTRA Sverige

Through its involvement with CHARMEC, SYSTRA has significantly enhanced its networking capabilities, built and shared knowledge, increased brand awareness among students, and gained inspiration for new ventures and the further development of existing services, all of which benefit our clients. SYSTRA particularly values the network and access to the highly skilled research environment for complex topics. We also appreciate the opportunity to develop and enhance our employees' knowledge and experience in complex subject matters, enabling SYSTRA to contribute to and advance the business.

Trafikverket

CHARMEC has been a key partner in the EU initiative Europe's Rail, actively conducting research, co-ordinating research activities, and making significant contributions to advancing the railway sector across Europe. CHARMEC leads two of Trafikverket's ten centres of excellence: Wheelsets and Braking Systems, and Track Systems.

Results from research in materials, fracture mechanics, and dynamic wheel–rail interaction have contributed to new alarm thresholds for damaged wheels and revised procedures following alarms. This has reduced capacity consumption in the infrastructure by decreasing the need for inspections after alarms, thereby enhancing capacity without compromising system safety. CHARMEC provides valuable insights into the performance of composite brake blocks under various operating conditions, which are utilised in the evaluation of regulations. The Swedish Transport Administration (Trafikverket) aims to achieve a low life cycle cost (LCC) for the infrastructure. One product intended to support this goal is Under Sleeper Pads (USP), designed to reduce ballast degradation. CHARMEC has analysed the benefits of USP and supported Trafikverket in its decision-making.

CHARMEC has also provided expert support in the restoration of the Iron Ore Line (Malmbanan) following the major derailment in Vassijaure during the winter of 2023/24. CHARMEC's expertise contributed to a control programme that enabled the railway to operate, albeit at reduced capacity, until the track could be fully restored to standard condition.

Professor Anders Ekberg has been partially employed at Trafikverket during Stage 10 to support the implementation of research findings. Over the years, CHARMEC has developed highly skilled professionals who have contributed significantly to Trafikverket. In the past three years, two PhD graduates, Emil Aggestam and Michele Maglio, have been employed at Trafikverket.

voestalpine Railway Systems

Understanding the mechanisms of crack initiation and crack growth in rails caused by repeated wheel–rail contact loading is crucial for voestalpine. During Stages 5 to 10, the co-operation with CHARMEC has focused on simulation models for the early growth of cracks, the prediction of crack propagation directions and wear, and the propagation of squats. These studies will continue in more detail during Stage 11. For voestalpine Railway Systems, the co-operation with CHARMEC has led to a better theoretical understanding of dynamic forces, stresses, and material behaviour within rails and turnouts. Previous research was focused on the development of an integrated simulation tool to predict plastic deformation, wear, and rolling contact fatigue over the life span of rails and crossings for different materials. This activity will also continue in Stage 11.

Wabtec Faiveley Nordic

The ongoing renewal of block braking systems is driven by the need for higher train speeds, increased axle loads, and lower noise levels. Wabtec is continuously developing new tread-braking solutions for the global market. A comprehensive approach, combining theoretical models and results from rig and field tests, has been developed together with CHARMEC. The tread braking of freight and passenger wagons should be optimised to achieve high braking power, low wear on blocks and wheels, and reduced noise levels from the wheels. The CHARMEC projects address the extremely high level of safety and reliability required for these systems. The new full-scale brake test rig at Chalmers, established with support from Wabtec, will be of great importance for further development of tread brakes.

SPECIAL EVENTS AND ACHIEVEMENTS (Stage 10)

Board meetings relocated and digitalised

Five of the twelve meetings of the CHARMEC Board during Stage 10 were combined with visits to organisations outside Chalmers: SJ in Solna on 24 May 2022, Atkins Sverige (now SYSTRA Sverige) in Stockholm on 30 November 2022, Trafikverket in Stockholm on 11 May 2023, Heidelberg Materials in Vislanda on 28 November 2023, and Wabtec Faiveley in Landskrona on 2 May 2024. Due to the coronavirus pandemic and its effects, the meeting on 14 September 2021 was held fully online, while the meeting on 9 December 2021 was held primarily online. The subsequent meetings were held both in person and online. From May 2020, the seminars given in connection with the Board meetings could also be followed via the internet.

Leaving members

With due acknowledgement from CHARMEC, the Board members Erik Kihlberg of Lucchini Sweden (2009–2022), Per Lövsund of Chalmers (2009–2023), Markus Gardbring of Green Cargo (2018–2024), and Maria Edén of Atkins (2021–2023) left the Board during Stage 10. The members of the Board for Stage 11 are listed on page 93.

Trafikverket

Trafikverket (the Swedish Transport Administration) is responsible for all modes of transport in Sweden – on roads and railways, at sea, and in the air – and it builds, maintains, and operates the entire national railway infrastructure. Trafikverket provides a basic contribution to CHARMEC's research, as well as to the centre's training and examination of doctoral students in railway mechanics. The chair of the CHARMEC Board has been held by Banverket/Trafikverket since the centre's inception in 1995. On 1 April 2024, CHARMEC's Anders Ekberg commenced a 40% employment at Trafikverket. The purpose of this employment is to bridge the gap between research and implementation by enhancing communication about both research results and needs. Initially, the primary focus will be on EU projects, particularly the EU project IAM4RAIL see page 61.

Research and Innovation Day at Trafikverket

Annually, in May, Trafikverket organises The Research and Innovation Day. On 4 May 2022, a presention was given by Claes Tingvall of Trafikverket, who is also an adjunct professor at Chalmers. He highlighted research initiatives focused on creating change in railway safety. Other presentations ranged from overviews to a more detailed description of digitalisation aimed at controlling electrified vehicle fleets. Anders Ekberg participated.

Transportstyrelsen

Transportstyrelsen (The Swedish Transport Agency) works to achieve good accessibility, high quality, secure and environmentally aware rail, air, sea, and road transport. It has the overall responsibility for drawing up regulations and ensuring that authorities, companies, organisations, and citizens abide by them. During Stage 10, CHARMEC's Tore Vernersson has continued to be involved in work on the winter tread-braking performance of composite brake blocks. He has also been part of a Swedish group of experts working for Transportstyrelsen, see project SD11 on page 53. Additionally, project SP33 has been discussed in meetings with Transportstyrelsen, see page 64.

Järnvägsbranschens samverkansforum

Järnvägsbranschens samverkansforum (JBS; Railway Sector Co-operation Forum) was formed in 2016 by actors from across the Swedish railway sector to drive railway improvement work. JBS organises an annual conference and a strategy seminar. During Stage 10, CHARMEC was represented at two of these conferences, which covered important areas such as punctuality, traffic information, skills supply, research, and data sharing.

VINNOVA

VINNOVA (Sweden's Innovation Agency) played a central role (following NUTEK) in the establishment of CHARMEC. During Stage 10, this agency financed the major part of project SP37, see page 68.

Mistra InfraMaint

MISTRA InfraMaint is a Swedish research programme focusing on smart maintenance. The programme has approved a grant to finance the major part of project TS25, which commenced at the beginning of Stage 11, see page 30.

UIC

The International Union of Railways (UIC) has funded a study at CHARMEC on "Brake blocks wheel interaction" with Tore Vernersson serving as the convenor of the working group "Wheel design worst case scenario assessment", see project SD11. Results from our work in the EU-project In2Track3 have been presented to UIC's Track Expert Group, see project EU21.

SPECIAL EVENTS … (cont'd)

Areas of Advance

Chalmers University has profiled its research activities around six Areas of Advance (*Swedish: Styrkeområden*). Two of these areas related to CHARMEC are Materials Science, in which CHARMEC provides applications that are extreme in many respects, and Transport, in which railway mechanics issues are crucial for a competitive railway transport system. We participate in seminars such as All Researchers' Day, organised by the area Transport, and some of our researchers have received financial support from them. Our projects "Sustainable railway asset management", "Integrated track design for reduced noise effects", "Single sensor condition monitoring for noise and deterioration in railway crossings", and "Reduced material consumption in railway operations", see projects SP32, SP35, SP36 and SP38 on pages 63, 66, 67, and 69, are financed by the Area of Advance Transport. This area is the host Area of Advance for CHARMEC, with a representative on the CHARMEC Board, see page 8.

KTH Railway Group

At KTH (the Royal Institute of Technology in Stockholm), our Professor Roger Lundén serves on the Board of the KTH Railway Group, and Professor Sebastian Stichel, Director of the Railway Group until 2024, serves on the Board of CHARMEC. Several of CHARMEC's doctoral students have taken general courses in railway technology at KTH. CHARMEC's senior researchers participate in examination committees for PhD theses and act as discussion leaders at licentiate seminars at KTH, and, similarly, KTH's senior researchers serve at Chalmers. Collaboration also takes place between research groups at KTH and Chalmers, for example in the European projects. KTH has been represented in the joint reference group for projects TS20, MU22, MU30, MU35–38, and MU40–41.

JVTC at LTU

Collaboration with Luleå JVTC (the Railway Research Centre at Luleå University of Technology in northern Sweden) takes place within the European projects. Professor Uday Kumar, who was Director of JVTC until 2023, is invited to the CHARMEC Board meetings, and, similarly, CHARMEC's Director Anders Ekberg is invited to the JVTC Board meetings.

DTU

During Stage 10 and earlier, Johan Ahlström, in projects MU30, MU35, and MU36 co-operated with researchers at DTU (Technical University of Denmark) to enable advanced microscopy, X-ray tomography, and synchrotron X-ray diffraction experiments. He and his research group regularly attend the annual Risø International Symposium on Materials Science and Engineering in Denmark.

RTRI

During Stage 10, CHARMEC continued its co-operation in project SD11 with the Railway Technical Research Institute (RTRI) in Tokyo (Japan). Eric Voortman Landström was a guest researcher at RTRI for three months in spring 2024, working on thermomechanical testing of wheels, see project SD11. Dr Katsuyoshi Ikeuchi from RTRI visited CHARMEC on 11 June 2024.

Semi-annual reports

Every six months, on 31 December and 30 June, all CHARMEC leaders of current projects prepare a two-page report on the progress of their projects during the preceding six months. The ten headings specified by the Board for each report are: Background and aims, Previous reports, Reference group, Work performed, Results achieved, Published material, Future plans, Check against initial schedule, Follow-up of budget, and Miscellaneous. All these two-page reports are edited, compiled into a document (about 50 pages), and submitted to the CHARMEC Board before their next meeting, where the reports are studied and discussed. All semi-annual reports have been written in English since 30 June 2003. During Stage 10, the editing was done by Roger Lundén, Jens Nielsen, and Bengt Åkesson.

Impact from CHARMEC projects

Starting in 2019, a list of foreseen impacts from the results of ongoing doctoral research projects has been added at the end of the semi-annual reports under the four headings: Long-term, Short-term, Academic implementation, and Industrial implementation. In CHARMEC's reporting of each doctoral dissertation, a list entitled "Implementable results" is being added.

Project Reference Groups

Most of CHARMEC's projects have had a Project Reference Group (PRG) since Stage 3. A PRG serves as a forum for the informal presentation and discussion of research results and for the planning of future activities (within the framework decided by the Board for the overall project plan). The mutual transfer of knowledge between researchers and industry (including Trafikverket) should be furthered, and the implementation in industry promoted. Doctoral students should be encouraged by the PRG to make study visits and to learn about the activities of the centre's partners. Employees of these partners should be encouraged to spend time working at Chalmers. A PRG meets once or twice a year, and the project leader is the convener. Several projects have a joint PRG.

At a meeting (2008:2), the Board decided that all doctoral projects should have a PRG, that notes should be taken at all PRG meetings, that these notes should be sent to CHARMEC's Director and archived, and that the locations and dates of the PRG meetings should be listed in the semi-annual reports. The directives for the PRG have been continuously updated since 2001.

Doctoral examinations

Our 60 doctoral examinations in railway mechanics are listed on page 71. As shown, six of these took place during Stage 10 and nine during Stage 9.

Appointment of docent

The highest academic qualification in Sweden (above the doctor's level) is that of "docent". On 8 September 2023, Astrid Pieringer (doctor in project VB10 and leader of projects VB12 and VB13) held her docent lecture "High-frequency wheel/rail interaction – Consequences, modelling, and possibilities" and was appointed. The reviewing experts were Professor Stefan Lutzenberger from Technische Universität München, Munich (Germany), and Professor Olivier Chiello from Université Gustave Eiffel, Bron (France).

Post-doc and Assistant Professor positions

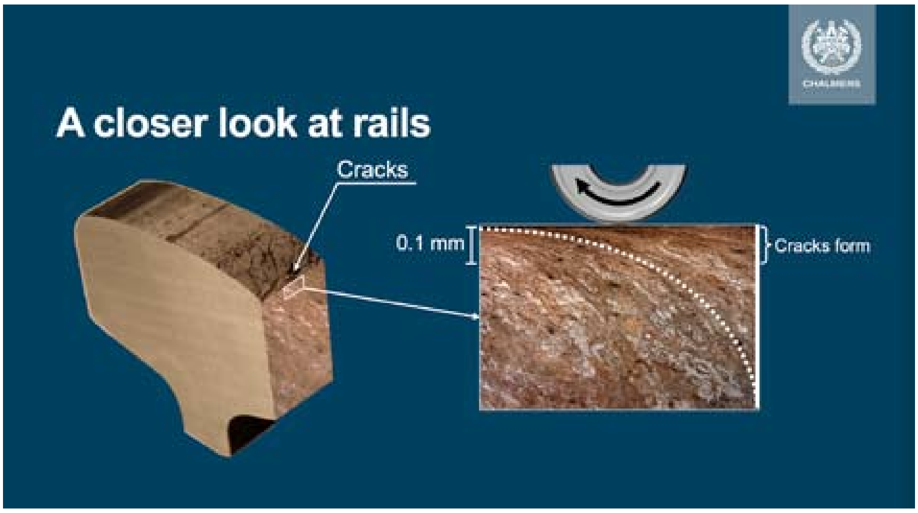
Knut Andreas Meyer, who completed his doctorate in project MU34 in October 2019, started a two-year post-doc in September 2020. However, he left Chalmers in July 2021 for a position at TU Braunschweig (Germany) but continued to serve as assistant supervisor in project MU41, see page 51. From October 2024, Knut Andreas is again employed at Chalmers, now as a tenure-track Assistant Professor, and is involved part-time in CHARMEC projects.

Inauguration of professors

Chalmers University holds traditional inauguration ceremonies for those who have been promoted to, or gained, a permanent position as professor, as well as for new research and visiting professors, adjunct professors, artistic and affiliated professors, and professors of the practice. On 18 March 2022, a total of 62 professors were inaugurated in the hall Runan at Chalmers Student Union Building. One of them was CHARMEC's Anders Ekberg, who had been promoted to professor on 1 December 2019 by President Stefan Bengtsson of Chalmers University.

Doctoral degree conferment ceremony

Every year, in May or June, Chalmers stages a ceremony for the conferment of higher degrees, in which those being awarded both PhDs and honorary doctorates take part. On 11 June 2022, in the Gothenburg Concert Hall, three CHARMEC doctors were awarded (out of an annual total of about 150 doctors at Chalmers University). They were Knut Andreas Meyer (project MU34), Rostyslav Skrypnyk (project TS17), and Mandeep Singh Walia (project SD10). Additionally, two CHARMEC-related 50-year Jubilee Doctorates were conferred: Professor Jan Torin (project SD3) and Professor Nils-Erik Wiberg (project VB9). At these ceremonies, the promotor (the person who conducts the ceremony) and one of the promovendi (the people who are being awarded a doctoral degree) give a presentation of their research. This time, the promovendus was Knut Andreas Meyer, who gave a brilliant lecture on his research entitled "A closer look at rails".



Picture from Knut Andreas Meyer's presentation at the Doctoral degree conferment ceremony in Gothenburg Concert Hall on 11 June 2022

Guest researchers

Doctoral student Lorenzo Ghidini from the University of Brescia and Lucchini RS in Italy spent April to June and December 2023 at Chalmers studying thermomechanical problems in braking, closely related to our projects SD11 and SP34. Together with CHARMEC researchers, he attended the Train&Rail fair in Älvsjö (Sweden) and the 20th International Wheelset Congress (IWC 2023) in Chicago, IL (USA), see page 87. Doctoral student Arianna Cavallo from Politecnico di Milano spent March to September 2024 with us working on an axle-mounted sensor system for detecting wheelset damage, which relates to our project TS20. Doctoral student Mohammad Shafiei from the University of Huddersfield (UK) was a guest from June to August 2024, working on condition monitoring of switches & crossings, which has connections with our project TS21.

INNOTRACK's project manager Björn Paulsson (left) and technical and scientific co-ordinator Anders Ekberg outside the UIC office in Paris. Photo taken in 2009

Björn Paulsson – a CHARMEC veteran

Former employee of Trafikverket in Borlänge and co-worker at UIC in Paris, Dr h c Björn Paulsson, has continued his engagement with CHARMEC. During Stage 10, he contributed to projects TS24, EU21, and SP33, see pages 28, 57 and 64. Björn Paulsson served as the first chairman of the CHARMEC Board from 1995 to 2008.

Some more CHARMEC veterans …

Professor Bengt Åkesson turned 90 in early June 2022. He initiated CHARMEC in 1995 and our early railway activities in 1987, serving as the centre's director until 1997. Since then, he has contributed to CHARMEC on a part-time basis, which has been and is greatly appreciated.

In 1987, Bengt Åkesson engaged **Dr Anders Frid** (then a doctoral student in solid mechanics) in a project for Sura Traction (now Lucchini Sweden) in Surahammar. Dr Frid was subsequently employed by ABB Corporate Research / Adtranz / Bombardier, and later by Epsilon / ÅF / AFRY. Throughout these years, he remained active in CHARMEC projects or as the manager in charge of CHARMEC contacts. He left for other responsibilities in October 2023.

Professor Jens Nielsen turned 60 in July 2023. He was employed at Chalmers in 1988 and defended his doctoral dissertation in 1993. Although CHARMEC did not formally start until 1995, Jens is considered CHARMEC's first doctoral graduate. His supervisors were Tore Dahlberg and Bengt Åkesson. In 1998, Jens Nielsen was hired full-time from the consulting companies Prosolvia / Epsilon / ÅF in rail research at CHARMEC. Jens became a docent in 2000 and served as an adjunct professor from 2006. After working as a consultant for 20 years, he was employed by Chalmers in 2018 as a research professor. Jens Nielsen's major contributions to CHARMEC can be studied in all of our ten Triennial Reports.

Docent Tore Vernersson was employed as a doctoral student 1994 and became a Licentiate of Engineering in project VB1 in 1997. He then took employment at Epsilon. Soon after, he was rehired by CHARMEC from Epsilon (later ÅF and AFRY), continuing for more than 25 years! He gained his doctoral degree in 2006 and became a docent in 2016. At last, Tore was employed by Chalmers in April 2024. A recent result of Tore's long-term efforts is our new brake test rig, see project SP34.

Exchange with voestalpine

As in previous years, meetings between CHARMEC researchers and our Austrian colleagues at voestalpine in Leoben and Zeltweg were held twice a year during Stage 10. Experts from the Materials Center Leoben, affiliated with the University of Leoben, and the Competence Center Virtuelles Fahrzeug (ViF) in Graz were invited to these two-day workshops. Additionally, experts from Linmag Rail Service and Railway Infrastructure Design (RID) at TU Graz were invited and participated on some of the occasions. The six meetings during Stage 10 were held on 17 January 2022

Study visit during the workshop with voestalpine in January 2023 to a tunnel of the Koralmbahn railway project, which includes 130 km of new high-speed rail between Graz and Klagenfurt in Austria

online, 17–18 May 2022 in Gothenburg, 16–17 January 2023 in Leoben and Zeltweg, 15–16 June 2023 in Gothenburg, 15–16 January 2024 in Leoben and Zeltweg, and 10–11 June 2024 in Gothenburg, being the 42nd workshop with voestalpine.

Lucchini

Bilateral agreements have been in place since 1987 between Lucchini Sweden (formerly Sura Traction, ABB Sura Traction 1990–1996, Adtranz Wheelset 1996–2000) in Surahammar and Chalmers Mechanics and Maritime Sciences (formerly Chalmers Applied Mechanics and, earlier, Chalmers Solid Mechanics). CHARMEC personnel have continuously assisted the Lucchini company and its predecessors in the design, analysis, testing, documentation, and marketing of wheelsets. Roger Lundén has previously represented Lucchini Sweden in the CEN and ERWA committees, see Triennial Report Stage 8 on page 72. The collaboration involves the parent company Lucchini RS in Lombardy, Italy. Today, wheelsets are manufactured, and wheelsets and bogies are maintained in Surahammar. Michele Maglio, in project TS20, made a four-week research visit to Lucchini RS in January to February 2022. A study visit to Lucchini RS was organised in April 2022, with five persons from CHARMEC, three from SweMaint, and two from Lucchini Sweden participating.

Lecture on Railway Mechanics

On 1 June 2023, Anders Ekberg and Lorenzo Ghidini from the University of Brescia and Lucchini RS delivered a lecture on Railway Mechanics, focusing on types of damage and the functional requirements of railway wheels. The 4-hour lecture was presented in Swedish in the morning and in English in the afternoon. It was a well-attended event, with approximately 80 participants at Surahammar Folkets Hus. In conjunction with the meeting, a visit to Lucchini Sweden's workshop was also organised. The meeting was part of Lorenzo Ghidini's guest research visit to CHARMEC.

Green Cargo's three-axle locomotives

During Stage 10, CHARMEC has continued to assist Green Cargo and Trafikverket in the approval process for locomotives with three-axle bogies operating on the Swedish infrastructure.

A 40-tonne ingot placed in the 4 200-tonne open-die forging press (now replaced by a new 7 000-tonne press) to obtain a special tool steel block at Lucchini RS in Italy

Online event for Alstom

At an online event on 7 March 2024, Michele Maglio presented his doctoral dissertation titled "Influence of railway wheel tread damage and track properties on wheelset durability – Field tests and numerical simulations", and Klara Mattsson presented her MSc thesis titled "Wheel-rail impact loads generated by wheel flats – Detector measurements and simulations".

IRR Huddersfield

During Stage 10, CHARMEC continued its collaboration with the Institute of Railway Research (IRR) at the University of Huddersfield (UK). A special issue related to the Switches & Crossings simulation benchmark was jointly organised by Björn Pålsson (CHARMEC) and Yann Bezin (IRR) and was published in Vehicle System Dynamics in 2023. Doctoral student Mohammad Shafiei from IRR was a guest at CHARMEC during the summer of 2024, see above.

Brake test rig

The Swedish brake test rig on the Lucchini premises in Surahammar, see page 75, was decommissioned during Stage 8, and results from experiments performed at RTRI in Japan have since been utilised by us. Following a decision by the CHARMEC Board, the design and construction of a new brake rig in a laboratory hall at Chalmers Mechanics and Maritime Sciences commenced during Stage 9 and was completed during Stage 10. For further details, see projects SD11 and SP34 in the Triennial Report Stage 9 on pages 54 and 73, and in the present report on pages 53 and 65.

CM2022

The International Conference on Contact Mechanics and Wear of Rail/Wheel Systems, abbreviated CM and held every three years, is central to CHARMEC's activities. Since September 2018, our Anders Ekberg has served as chairman of the international committee for these conferences. Chalmers/CHARMEC has contributed to these conferences even before the establishment of CHARMEC in 1995, with the first contribution by Roger Lundén at CM1990 in Cambridge (UK). CHARMEC organised the CM2003 conference, see Triennial Report Stage 3 on page 62. Delayed by one year because of the pandemic, CM2022 was held in Melbourne (Australia) on 4–7 September 2022. The conference was attended by 165 participants from 16 countries, including 8 researchers from CHARMEC (one of whom participated online). They contributed seven oral presentations and chaired three sessions. CM2025 will be held in Tokyo (Japan) on 22–26 September 2025.

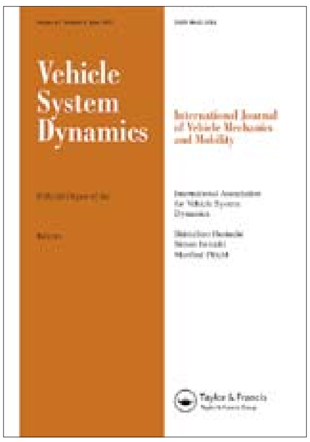
IAVSD and Vehicle System Dynamics

The 27th International Symposium on Dynamics of Vehicles on Roads and Tracks (IAVSD2021) was organised by the International Association for Vehicle System Dynamics (IAVSD) online, due to the pandemic, from St Petersburg (Russia) on 17–19 August 2021. Two oral contributions were given by CHARMEC researchers, see projects TS21 and TS22 on pages 22 and 25. Further, the 28th International Symposium (IAVSD2023) was held in Ottawa (Canada) on 21–25 August 2023. Jens Nielsen presented an invited keynote lecture, co-authored with Simon Iwnicki (University of Huddersfield, UK) and Gongquan Tao (Southwest Jiaotong University, Chengdu, China), see project TS8 on page 14. Three oral contributions were given by CHARMEC researchers, see projects TS22, TS23 and TS24 on pages 25, 27 and 29. Chalmers/CHARMEC has contributed to these conferences even before the establishment of CHARMEC in 1995 and was part of the organising committee for IAVSD2019 in Gothenburg, see Triennial Report Stage 9 on page 83. Since 2009, our Jens Nielsen has been a member of the IAVSD International Scientific Committee. IAVSD2025 will be held in Shanghai (China) on 18–22 August 2025.

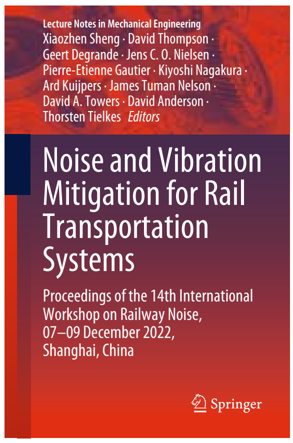
Since 2022, Jens Nielsen has been a member of the Editorial Board of the journal Vehicle System Dynamics.

IWRN14

The 14th International Workshop on Railway Noise (IWRN14) was held, mainly online due to the pandemic, in Shanghai (China) on 7–9 December 2022. Two oral contributions were given by CHARMEC researchers, see projects VB12 and VB13 on pages 32 and 34. Our Jens Nielsen is a member of the international committee for the IWRN workshops. IWRN15 will be held on Isla de la Toja (Spain) on 15–19 September 2025.



Front cover of the journal Vehicle System Dynamics



Front cover of proceedings featuring 78 peer-reviewed articles from IWRN14

Summaries of interesting conference papers

A tradition at CHARMEC is that those of our researchers attending a conference should write a short summary of the contents of the two or three contributions they found most interesting. These summaries are then made available to all CHARMEC researchers and Board members.

Iron Ore Line

During Stage 10, CHARMEC has continued its involvement in various activities and research regarding heavy haul transports on Malmbanan (the Iron Ore Line in northern Sweden and Norway). Anders Ekberg has assisted Trafikverket in evaluating the consequences of increased axle load (STAX 30+) and investigating the effect of Under Sleeper Pads (USP). In December 2023, a serious derailment occurred on Malmbanan, halting traffic for several weeks. A framework developed by CHARMEC for assessing risks of track buckling was employed, along with fracture mechanics assessments, to make the decision on resuming limited traffic. The findings are available in a public report, see further project MU22. Anders Ekberg and Tore Vernersson have since assisted the Swedish Accident Investigation Authority in establishing the causes of the derailment. Additionally, Malmbanan is studied from several other aspects in our research, see, e g, projects TS22, VB12, SD11, EU21, and SP38.

Peer reviewing and keeping in touch

CHARMEC's project leaders and researchers are heavily involved in the peer reviewing of manuscripts for scientific journals, including: Applied Acoustics, Composites Part A: Applied Science and Manufacturing, Computational Mechanics, Computer Methods in Applied Mechanics and Engineering, Computers and Structures, Engineering Failure Analysis, Engineering Fracture Mechanics, Engineering Structures, European Journal of Mechanics – A/Solids, Fatigue & Fracture of Engineering Materials & Structures, IMechE Journal of Materials. Design and Applications, IMechE Journal of Mechanical Engineering Science, IMechE Journal of Rail and Rapid Transit, Ingegneria Ferroviaria, International Journal for Numerical Methods in Engineering, International Journal of Damage Mechanics, International Journal of Fatigue, International Journal of Plasticity, Journal of Manufacturing Processes, Journal of Materials Research and Technology, Journal of Thermal Stresses, International Journal of Rail Transportation, Journal of Materials Engineering and Performance, Journal of Sound and Vibration, Journal of the Mechanics and Physics of Solids, Materials Characterization, Mechanical Systems and Signal Processing, Measurement, Mechanics of Materials, Mechanics Research Communications, Networks and Heterogeneous Media, Railway Engineering Science, Science and Technology in Joining and Welding, Transportation Geotechnics, Tribology International, Vehicle System Dynamics, Wear, Welding in the World, and ZAMM. In addition, we review papers submitted to international congresses, conferences, symposia, and workshops, and we act as experts in academic promotion issues. All of these activities are valued by us as an important way to stay in touch with international developments in science and technology, and their railway applications.

Nordic Track Technology Engineering Training

This is a four-week course titled Nordisk Banteknisk Ingenjörs-Utbildning (NBIU) in Swedish, held annually for participants from Denmark, Finland, Norway and Sweden. CHARMEC's Professor Jens Nielsen contributes with the lecture "An introduction to track dynamics". During Stage 10, the 36th, 37th, and 38th NBIU took place, with Jens Nielsen participating for the 23rd, 24th, and 25th times.

Nordic Rail Fair

Nordic Rail at the Elmia Exhibition Centre in Jönköping (Sweden) commenced in 1995 and was held bi-annually. On ten occasions, CHARMEC, in various constellations, shared a stand with the KTH Railway Group, Luleå Railway Research Centre (JVTC), VINNOVA, and The Swedish National Road and Transport Research Institute (VTI). Our research projects were displayed, and printed materials were distributed to visitors. Since 2017, CHARMEC has only attended the exhibition. The 14th Nordic Rail was held on 10–12 October 2023, with two of our doctoral candidates, along with Professor Roger Lundén, visiting the fair, see page 50. The next exhibition will take place on 8–9 October 2025, now under the name Elmia Infra Rail.

Nordic seminars on Railway Technology

The Research Group TerraRail at Tampere University organised the 21st Nordic Seminar on Railway Technology in Tampere (Finland) on 21–22 June 2022, with approximately 130 participants. The 22nd seminar was arranged by the KTH Railway Group on 18–19 June 2024 at KTH in Stockholm with around 180 participants. From CHARMEC, 10 and 17 persons, respectively, took part and gave presentations. These are listed under the project descriptions in the previous section.

Swedtrain

Swedtrain is the Swedish Association of Railway Industries. It is one of the organisations that arrange the annual Järnvägsdagen (The railway day) in Sweden, where researchers from CHARMEC participate. Our student, Klara Mattsson, received the 2023 Swedtrain Award for Best Master's Thesis. Her work, titled "Wheel-rail impact loads generated by wheel flats – Detector measurements and simulations", was supervised by Lars Fehrlund and Andreas Lundin of Green Cargo, Matthias Asplund of Trafikverket, and Jens Nielsen, Michele Maglio and Tore Vernersson of CHARMEC. Klara Mattsson presented her work at Swedtrain's spring meeting in May 2024. She has also presented her work in online events for the Wheelset Management Group at the Railway Safety and Standards Board (RSSB) in the UK and for engineers at Alstom.

Master's student Klara Mattsson in the driver's seat during a study visit to Alstom's maintenance workshop in Gothenburg in November 2021. The visit was organised as part of the course in Railway Technology at Chalmers

VTI

The Swedish National Road and Transport Research Institute, VTI, has its headquarters in Linköping. Docent Peter Torstensson, who earned his doctorate in 2012 through project TS11, is Research Director for the Division of Environment at the VTI office in Gothenburg, but remains involved in CHARMEC research. In March 2023, he was appointed Adjunct Docent at Chalmers. VTI contributes to projects TS8, TS18, TS25, and VB12, see pages 14, 15, 30 and 31.

EU projects

Since its inception in 1995, CHARMEC has undertaken European Union (EU) projects, starting with EU1 to EU5 from 1996 to 1999, and continuing up to EU21 through EU27 during Stage 10, see pages 57–62. Recently, these EU projects have been part of the Horizon Europe Programme and have fallen under the Europe's Rail Joint Undertaking, see below.

JRRT

From 2024, CHARMEC's Tore Vernersson is a member of the Editorial Board of the IMechE Journal of Rail and Rapid Transit (JRRT). Editor of the journal is Professor Simon Iwnicki of Huddersfield University in the UK. Many research results in railway mechanics from Chalmers/CHARMEC have been published in this periodical (more than 70 articles up to 2024). IMechE stands for the Institution of Mechanical Engineers, which has its premises on Birdcage Walk in Westminster, London (UK). During the years 2005–2024, Roger Lundén was a member of the JRRT Editorial Board.

Study visit to SweMaint's maintenance workshop in Gothenburg in May 2022, organised as part of the course in Railway Technology at Chalmers

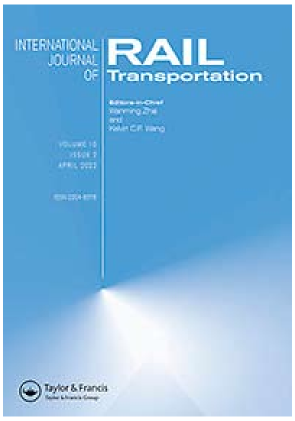
SPECIAL EVENTS … (cont'd)

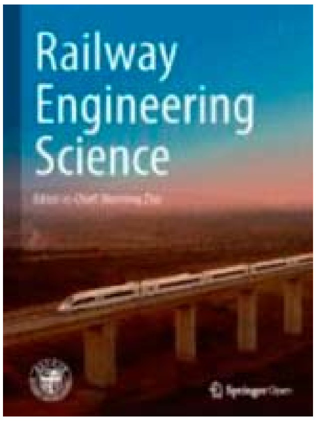
Ingegneria Ferrovia

Since 2009, Anders Ekberg has been a member of the Editorial Board of Ingegneria Ferroviaria.

IJRT and Railway Engineering Science

Since 2013, Jens Nielsen has been a member of the Editorial Board of the International Journal of Rail Transportation (IJRT). This is an online journal with Professor Wanming Zhai of Southwest Jiaotong University (China) and Dr Kelvin Wang of Oklahoma State University (USA) serving as Editors. Since 2019, Jens Nielsen has also been a member of the Editorial Board of the journal Railway Engineering Science, where Professor Wanming Zhai is also the Editor (he visited CHARMEC in 1998, see page 55 in Triennial Report Stage 2). Jens Nielsen is also a member of the Editorial Board of the journal Vehicle System Dynamics, see page 82.





Master's programme in Mobility Engineering

This programme was launched at Chalmers University in the autumn 2021, with four subprogrammes: Automotive, Naval, Aerospace, and Rail. CHARMEC has contributed to the formulation of the programme, particularly its "Rail" part, and the content has been discussed by the CHARMEC Board. Anders Ekberg, Elena Kabo, Jens Nielsen, and Björn Pålsson have developed the new course "Railway Technology". Elena Kabo and Anders Ekberg have created the applied course "Railway Technology Project". Additionally, CHARMEC researchers have contributed to the course "Introduction to Propulsion and Energy Systems for Transport". Both national and international students participate in this Master's programme. The courses have now been run for four years, and student evaluations have been very positive. The Rail courses have seen increasing interest, with 18 students registered in the Railway Technology course in 2024. Students have also carried out MSc theses work in the railway area. See also projects MU22 and SP32 on pages 35 and 63.

Advanced Fatigue Design

During Stage 10, a graduate course under this heading was delivered by Anders Ekberg, focusing on multiaxial fatigue, non-linear fracture mechanics, contact phenomena, and thermal effects in fatigue. The content is highly relevant for railway applications. Doctoral students from CHARMEC participated.

Rolling Stock Summer School 2023

The Rolling Stock Summer School 2023 took place from 17 to 21 July 2023 in Lecco (Italy). The focus was primarily on rail dynamics and rolling contact, but insights were also provided in several other areas such as aerodynamics, axle fatigue, and the practical aspects of testing and approving rail vehicles. Participants from CHARMEC were Kourosh Nasrollahi, Henrik Vilhelmson and Eric Voortman Landström. Approximately 30 doctoral students attended. Some of the well-known lecturers were Professor Stefano Bruni (Politecnico di Milano), Professor Simon Iwnicki (University of Huddersfield), and Professor Mats Berg (KTH). The schedule mainly comprised lectures in the various areas, but also presentations of various group projects.

Shift2Rail

Shift2Rail was an initiative within the EU Horizon 2020 programme, aimed at "focused research and innovation in the rail area by accelerating the integration of new and advanced technologies into innovative rail product solutions". It is a so-called Joint Technology Initiative (JTI), which aims to establish public-private partnerships. Shift2Rail was approved by the EU in June 2014 with a total budget of MEUR 920. Trafikverket was one of nine founding members. Chalmers/CHARMEC was a linked third party to Trafikverket. See further pages 57–59 and Triennial Report Stage 9 on pages 57–62.

Europe's Rail

Within Horizon Europe, Shift2Rail (part of Horizon 2020) has been succeeded by the programme Europe's Rail, running from 2021 to 2027. CHARMEC has co-operated with Trafikverket, one of the 31 founding members of the Joint Undertaking (JU), in formulating research areas for the programme. The vision of Europe's Rail JU is "To deliver, via an integrated systems approach, a high-capacity, flexible, multimodal, sustainable and reliable integrated European railway network by eliminating barriers to interoperability and providing solutions for full integration, for European citizens and cargo". The mission statement of Europe's Rail is "Rail research and innovation to make rail the everyday mobility". Each of the research projects will belong to one of the seven Flagship Areas:

1. Network management planning and control & Mobility management in a multimodal environment
2. Digital & automated up to autonomous train operations
3. Intelligent & integrated asset management
4. A sustainable and green rail system
5. Sustainable competitive digital green rail freight services
6. Regional rail services / Innovative rail services to revitalise capillary lines
7. Innovation on new approaches for guided transport modes

There is also the Innovation Pillar, tasked with delivering "operational and technological solutions that contribute to a more efficient, flexible, and demand-led, yet safe and environmentally sustainable European railway system", and the System Pillar, which is "the generic system integrator for the Europe's Rail Joint Undertaking, and the architect of the future EU's railway system". The first calls for project proposals were launched in March 2022, with projects started in autumn 2022 and early 2023.

Trafikverket's Areas of Excellence

In 2021, in response to the challenges facing the railway sector, Trafikverket identified and established ten so-called Areas of Excellence for key research. This initiative aimed to renew, consolidate, and expand the existing co-operation with the four railway research centres: CHARMEC, KTH Railway Group, Luleå Railway Research Center/JVTC, and KAJT (Capacity in the Railway Traffic System, in Swedish: *Kapacitet i järnvägstrafiken*). Agreements with a ten-year horizon between Trafikverket and these centres were signed in spring 2021. The establishment of the Areas of Excellence is also expected to attract more partners, bringing in new funding and thereby increasing the total supply of qualified research.

Senior Lecturer Joosef Leppänen at Chalmers Department of Architecture and Civil Engineering co-ordinates Excellence Area 4, Civil engineering structures and foundations

The ten Areas of Excellence are:

1. Vehicle technology / Vehicle dynamics
2. Wheelsets and brake systems
3. Track technology
4. Civil engineering structures and foundations
5. Electric power / Power supply and traction systems
6. Safety signalling systems
7. Traffic planning and traffic control
8. Operation and maintenance
9. Capacity and punctuality
10. The railway from a system perspective

Chalmers/CHARMEC is carrying out work in Areas 2, 3, and 4, and to some extent in Areas 1, 8, and 10. Furthermore, Chalmers/CHARMEC is co-ordinating Areas 2, 3, and 4 (in consultation with KTH and Luleå University of Technology regarding bridges). See further pages 12, 35, 92 and 93.

During Stage 10 and earlier, Pernilla Appelgren and Jonas Lindqvist from Chalmers Mechanics and Maritime Sciences provided assistance with financial issues

Previous Triennial Reports

Dark blue	1 July 2018 – 30 June 2021	98 pp
White	1 July 2015 – 30 June 2018	84 pp
Orange	1 July 2012 – 30 June 2015	132 pp
Black	1 July 2009 – 30 June 2012	128 pp
Yellow	1 July 2006 – 30 June 2009	104 pp
Green	1 July 2003 – 30 June 2006	94 pp
Red	1 July 2000 – 30 June 2003	81 pp
Blue	1 July 1997 – 30 June 2000	56 pp
Black	1 July 1995 – 30 June 1997	26 pp

All reports are available on
www.chalmers.se/charmec → Achievements

INTERNATIONAL CONFERENCES

During Stage 10 (and the months immediately following Stage 10) researchers from CHARMEC have participated in, and contributed to, the following major seminars, workshops, symposia, conferences and congresses (some of them held online because of the coronavirus pandemic):

47. Jahrestagung für Akustik – DAGA 2021 in Vienna (Austria) 15-18 August 2021

The 27th International Symposium on Dynamics of Vehicles on Roads and Tracks (IAVSD2021, online) in St Petersburg (Russia) 17-19 August 2021

The 11th International Conference on Residual Stresses (ICRS 11) in Nancy (France) 27-30 March 2022

The International Braking Technology Community & Event (Eurobrake 2022, online) 17-19 May 2022

The 13th World Congress on Railway Research (WCRR) in Birmingham (UK) 6-10 June 2022

The 21st Nordic Seminar on Railway Technology in Tampere (Finland) 21-22 June 2022

The European Workshop on Structural Health Monitoring (EWSHM 2022) in Palermo (Italy) 4-7 July 2022

The Fifth International Conference on Railway Technology (Railways 2022) in Montpellier (France) 22-25 August 2022

The 12th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM 2022) in Melbourne (Australia) 4-7 September 2022

The 11th International Symposium on Field Monitoring in Geomechanics (ISFMG 2022) in London (UK) 4-8 September 2022

The 42nd Risø International Symposium on Materials Science in Risø / Roskilde (Denmark) 5-9 September 2022

The 14th International Workshop on Railway Noise (IWRN 14) in Shanghai (China) 7-9 December 2022

49. Jahrestagung für Akustik – DAGA 2023 in Hamburg (Germany) 6-9 March 2023

The 20th International Wheelset Congress in Chicago, IL (USA), 8-12 May 2023

The 28th International Symposium on Dynamics of Vehicles on Roads and Tracks (IAVSD 2023) in Ottawa (Canada) 21-25 August 2023

The 10th Convention of the European Acoustical Association – Forum Acusticum in Turin (Italy) 11-15 September 2023

50. Jahrestagung für Akustik – DAGA 2024 in Hannover (Germany) 18-21 March 2024

The 9th European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS) in Lisbon (Portugal) 3-7 June 2024

53rd International Congress & Exposition on Noise Control Engineering (Inter-Noise 2024) in Nantes (France) 25-29 August 2024

The Sixth International Conference on Railway Technology (Railways 2024) in Prague (Czech Republic) 1-5 September 2024

The 6th SmartRaCon Scientific Seminar (SmartRaCon 2024) in San Sebastian (Spain) 23-24 October 2024

Photo from IWC 2023 at The Drake Hotel in Chicago, IL (USA), in May 2023. From left: Francesco Lombardo (Lucchini RS), Roger Lundén (CHARMEC), Lorenzo Ghidini (University of Brescia / CHARMEC), Eric Voortman Landström (CHARMEC), Tore Vernersson (CHARMEC), and Steven Cervello (Lucchini RS)

This report was authored in October 2022 by Lovisa Håkansson, Communications Partner at Chalmers.

On the right track – CHARMEC turns 25

"CHARMEC's research has contributed in many ways to improving the railway's ability to develop, build, and maintain both infrastructure and vehicles," says Ingemar Frej, senior advisor at the Swedish Transport Administration and chairman of the Board of CHARMEC, who along with around 60 guests from industry and academia took part in the competence centre's 25th anniversary, which was celebrated with pomp and circumstance at the end of September.

A few weeks ago, CHARMEC's much longed for 25th anniversary took place – a milestone that was celebrated with mingling and dinner at Chalmersska huset, entailed by a half-day seminar the following day. On site in the lavish premises on Södra Hamngatan to celebrate the anniversary were both CHARMEC colleagues as well as representatives from the centre's partners from academia and industry, including Ingemar Frej, CHARMEC's chairman of the Board as well as senior advisor and acting unit manager for Development at the Swedish Transport Administration: "It's great to meet people who have been involved in the work over the years. The dinner's speeches and seminars gave a very good picture of the activities that have been carried out for more than 25 years and the benefits they have provided," he says.

Jens Nielsen, Bengt Åkesson, and Roger Lundén

The anniversary celebration, which due to the pandemic took place two years after the actual 25th anniversary, was perhaps especially anticipated by the director of CHARMEC, Anders Ekberg: "It was very successful! Great fun to meet colleagues that you haven't seen for a long time due to the pandemic," he says.

Among the close to 60 invited guests were CHARMEC's founder Bengt Åkesson and the competence centre's first four doctoral students Mikael Fermér, Annika Lundberg, Åsa Sällström, and Jens Nielsen – the latter of whom served as toastmaster during the dinner – as well as the former board members Per Gullers and Hugo von Bahr. CHARMEC's PhD students Henrik Vilhelmson and Caroline Ansin were also present to take part in the celebrations. "It's really inspiring to be part of this! As a PhD student, it makes you feel quite special," says Henrik Vilhelmson, PhD student at Dynamics.

Around 60 guests celebrated the 25th anniversary of CHARMEC at Chalmersska huset

And Caroline Ansin, PhD student at IMS, who gave a speech during dinner, agrees: "I totally agree! I also get very inspired. In my speech, I mentioned three key words that I believe signify the work within CHARMEC: curiosity, commitment and community. And this becomes particularly obvious in contexts like these," says Caroline.

Emil Aggestam, Casey Jessop, and Caroline Ansin

Developing the railway – yesterday, today and tomorrow

The celebration was followed by an open anniversary seminar with lectures on CHARMEC's development and work over the years, on the implementation and utilisation of the centre's research, as well as on important research areas that characterise CHARMEC's work today. Among the speakers were representatives from SJ, the Swedish Transport Administration, Abetong, Green Cargo, and CHARMEC. And even for those "in the know" the seminar offered lessons to take away: "Even I, who work daily in the CHARMEC environment, learned a lot of new things," says Anders Ekberg, director of CHARMEC, who also takes the opportunity to mention a milestone from CHARMEC's history:

"I would like to highlight the research we have done on combining analyses. A simple example is the determination of forces when the trains roll on the tracks, combined with how running gears, tracks, and sleepers are broken down by these forces and how rolling noise and ground vibrations are generated by the damaged wheels. This ability to combine analyses applies not only between disciplines but also in how the analyses are done. Here we combine different types of numerical simulations with lab experiments and full-scale measurements. Together, this opportunity to combine disciplines and methods has been used in everything from investigations of the consequences of higher axle loads to more precise maintenance criteria and inspection intervals. At the seminar, several examples were shown of the large savings and efficiency gains this has generated. Among other things, Roger Lundén (CHARMEC's former director) recalled an evaluation commissioned by VINNOVA from 2013 which showed profits from our research of between SEK 1 035 and 1 430 million per year. It doesn't seem to have decreased since then," says Anders.

Jonas Ringsberg, Roger Deuce, and Anders Ekberg

Anders also believes that CHARMEC's opportunities to meet future challenges look promising: "One major challenge is that it's often taken for granted that the railway system and its components just work. It's easy to forget that the constant increase in traffic also causes the degradation to increase, while the possibilities for maintenance decrease and the consequences of breakdowns become ever greater. But we have very strong research that provides completely new opportunities to construct and maintain running gear and track. This is not only good for economy, capacity, and reliability, but also provides great environmental benefits as you extend the life span of the components. In this context, people like to talk about big data, digitalisation, AI, etc. I see it as our task to add the "intelligence" into these technologies: What data do we need, how do we collect and analyse these, how do we train AI and prevent false AI conclusions by combining AI with physical modelling?" explains Anders Ekberg.

And for the chairman of the Board, Ingemar Frej, there's no doubt about what CHARMEC's work over the past two and a half decades has meant for the railway's development at large. "CHARMEC's research has contributed in many ways to improving the railway's ability to develop, build, and maintain both infrastructure and vehicles. Several of the graduated doctors of technology have also been employed by the railway's actors, such as the Swedish Transport Administration, train operators, and supplying companies, and have contributed to the development of competence in the respective operations," he says.

FINANCIAL REPORT

This presentation details the cash and in-kind investments for Stage 10, broken down by party and programme area. The financial information regarding funds received and used is sourced from Chalmers' accounts for the CHARMEC Competence Centre and the accounts for each department's CHARMEC projects. The in-kind investments from the Industrial Interests Group and Chalmers have been calculated according to the principles outlined in the Principal Agreement for Stage 10, dated 16 August 2021.

Report per party

Budgeted cash and in-kind investments per party, according to the Principal Agreement for Stage 10, are presented in Table 1. Also included are cash contributions from Chalmers, Trafikverket, and VINNOVA that were not included in the Principal Agreement for Stage 10. Cash contributions from the EU are also included. In the Shift2Rail and Europe's Rail projects, Chalmers/CHARMEC is a so-called Linked Third Party, meaning that Chalmers/CHARMEC only has a contract with Trafikverket, although the funding partly originates from the EU and the finances are reported in a similar way as for an ordinary EU project.

Cash investments

The Principal Agreement for Stage 10 was distributed to Trafikverket and the Industrial Interests Group on 13 October 2021. At the same time, they were informed that payments from the partners to CHARMEC would be settled in a similar manner to previous stages. This meant that CHARMEC would invoice the Industrial Interests Group on six different occasions: 2021-11-01, 2022-03-01, 2022-09-01, 2023-03-01, 2023-09-01, and 2024-03-01. This proposal was accepted by all partners. However, due to the pandemic, it was agreed that SJ could pause their contribution during the first year of Stage 10. Trafikverket's contribution follows the co-operation agreement described below, with invoicing done once or twice per year.

A co-operation agreement on railway research between Chalmers University of Technology, the Royal Institute of Technology (KTH), Luleå Technical University, and Trafikverket was signed in April 2021. The contract is valid for ten years (1 January 2021–31 December 2030). For CHARMEC, this means an annual provision of kSEK 5000 for its activities in Trafikverket's Excellence Areas, see pages 86 and 93. For Stage 10, this agreement thus provides funding of kSEK 3 x 5000 + 2500 = kSEK 17 500, where kSEK 2500 is for the period 1 January – 30 January 2021, which is included in the budget for Stage 10. Additional funding for other projects is also mentioned in the co-operation agreement, which during Stage 10 has been fulfilled through the EU projects and projects TS24, SP33 and SP37, see below.

Table 1. Cash and in-kind contributions (kSEK) per party during Stage 10

Party	Cash		In-kind		Total	
	Budget	Paid	Budget	Performed	Budget	Paid/Performed
Chalmers	13 042	13 042	4 265	4 265	17 307	17 307
Alstom	1 800	1 800	750	369	2 550	2 169
Green Cargo	660	660	330	108	990	768
Heidelberg	777	777	357	16	1 134	793
Lucchini	1 485	1 485	600	631	2 085	2 116
SJ	440	440	–	–	440	440
SweMaint	162	162	162	0	324	162
SYSTRA	195	195	150	29	345	224
Trafikverket	19 367	19 367	–	–	19 367	19 367
voestalpine	2 317	2 317	2 460	3 239	4 777	5 556
Wabtec	810	810	600	453	1 410	1 263
EU Shift2Rail	34 118	34 118	–	–	34 118	34 118
Europe's Rail	4 924	4 924	–	–	4 924	4 924
VINNOVA	512	512	–	–	512	512
From Stage 9	9 876	9 876	–	–	9 876	9 876
Total	90 485	90 485	9 674	9 110	100 159	99 595

Note 1. Alstom: formerly Bombardier Transportation, Heidelberg: formerly Abetong, SYSTRA: formerly Atkins Sverige, and Wabtec (Faiveley): formerly Faiveley Transport Nordic
Note 2. The EU projects are partly financed by the EU and partly by Trafikverket

In November 2020, Trafikverket approved a project proposal from Chalmers/CHARMEC, providing one year of funding for the project SP33 "More robust switches through improved control of the switch rail" with a total budget of kSEK 680, of which ksek 420 was allocated to Stage 9 and kSEK 260 to Stage 10. In November 2021, Trafikverket approved five years of funding for the project TS24 "Risk analysis for derailment in switches" with a total budget of kSEK 6050, of which kSEK 1600 was allocated to Stage 10 and kSEK 4450 to Stage 11.

In June 2023, VINNOVA approved three years of funding for the project SP37 "Improved regulations and procedures for damaged wheels" with a total budget of kSEK 1 219, of which kSEK 512 was allocated to Stage 10 and kSEK 707 to Stage 11. In November 2023, Trafikverket approved an application for additional financing of project SP37 with a total budget of kSEK 656, of which kSEK 7 was allocated to Stage 10 and kSEK 649 to Stage 11. By the end of Stage 10, all the amounts for projects TS24, SP33, and SP37 had been invoiced according to their respective budgets for Stage 10.

In May 2021, Trafikverket and Chalmers signed a contract providing kSEK 28 402 to the EU21 project "In2Track3". Between January 2022 and April 2023, Chalmers and Trafikverket signed eighteen additional contracts for project EU21, providing a total of kSEK 7 716. In March 2023, and later during CHARMEC Stage 10, Trafikverket and Chalmers signed contracts providing kSEK 4 261, 13 400, 1 400, 3 722, and 800, respectively, to the five EU projects EU22 R2DATO, EU23 IAM4RAIL, EU24 RAIL4EARTH, EU25 TRANS4M-R, and EU26 FUTURE. In November 2022, voestalpine Railway Systems GmbH and Chalmers signed a contract providing kSEK 2 200 to the EU27 project "IAM4RAIL – High-Speed Turnouts".

Chalmers University supports CHARMEC financially. For Stage 10, the agreed amount was kSEK 2 160 centrally from the Department of Mechanics and Maritime Sciences and kSEK 2 673 from its Division of Dynamics. At the Department of Industrial and Materials Science, its Division of Material and Computational Mechanics contributed kSEK 3 016 and its Division of Engineering Materials kSEK 1 983. The Division of Technical Acoustics at the Department of Architecture and Civil Engineering contributed kSEK 535. Chalmers supports EU projects, which during Stage 10 meant a contribution of kSEK 2 384 + 191 = kSEK 2 575 to the projects EU21 and EU22 – EU27. Chalmers provided kSEK 100 for CHARMEC's winning of the 2019 Chalmers Impact Award for our contributions to methods for predicting crack formation in railway wheels and introducing harmonised load limits for railway transportation in Europe, see Triennial Report Stage 9. The money was used to organise CHARMEC's 25th Anniversary on 28 – 29 September 2022, see pages 88 – 89, which had been delayed due to the coronavirus pandemic.

Table 2. Budgeted and used cash and in-kind contributions (kSEK) during Stage 10, with the Industrial Interests Group and Chalmers shown separately, for each programme area and for management and administration

	Cash		In-kind industry		In-kind Chalmers		Total	
Programme area	Budget	Used	Budget	Used	Budget	Used	Budget	Used
TS	6 097	6 826	1 617	1 075	0	0	7 714	7 901
VB	930	1 110	240	25	0	0	1 170	1 135
MU	11 125	11 404	2 350	2 742	0	0	13 475	14 146
SD	6 022	6 095	802	881	600	600	7 424	7 576
EU	39 603	39 617	0	0	0	0	39 603	39 617
SP	2 379	2 742	400	122	3 065	3 065	5 844	5 929
Management	3 000	2 761	0	0	600	600	3 600	3 361
Total	69 156	70 555	5 409	4 845	4 265	4 265	78 830	79 665

Note 1 Budget under "Cash" is as of 10 October 2024. These amounts have been transferred to the projects

Note 2 In-kind contributions from Chalmers include the support kSEK 3 065 from Chalmers Area of Advance Transport in projects SP32, SP35, SP36, and SP38

Note 3 Additional kSEK 3 641 has been transferred to Chalmers Department of Architecture and Civil Engineering for their co-ordination and work in Trafikverket's Excellence Area 4, Civil engineering structures and foundations

Note 4 The balance in cash to be transferred to CHARMEC's Stage 11 by 30 June 2024 is kSEK 90 485 – 69 156 – 3 641 = kSEK 17 688

The following amounts in cash, totalling KSEK 28 013, due for CHARMEC's Stage 10, have been received as per agreements:

6 × KSEK 300	Alstom
6 × KSEK 110	Green Cargo
6 × KSEK 129.5	Heidelberg Materials
6 × KSEK 247.5	Lucchini Sweden
4 × KSEK 110	SJ
6 × KSEK 27	SweMaint
6 × KSEK 32.5	SYSTRA Sverige
3 × KSEK 5 000 + 2 500+ 1 867 = KSEK 19 367	Trafikverket
6 × KSEK 212	voestalpine Rail Technology
6 × KSEK 174	voestalpine Railway Systems
6 × KSEK 135	Wabtec Faiveley

From Trafikverket and the EU (through Trafikverket), KSEK 26 402 + 4 216 + 3 500 = KSEK 34 118 in cash have been received for the Shift2Rail project EU21, including the eighteen additional projects, in Stage 10. Additionally, from Trafikverket and the EU (through Trafikverket), KSEK 276 + 2 853 + 140 + 665 + 80 = KSEK 4 014 in cash have been received for the Europe's Rail projects EU22, EU23, EU24, EU25, and EU26 in Stage 10. From voestalpine Railway Systems GmbH and the EU (through voestalpine), KSEK 910 in cash have been received for the Europe's Rail project EU27 in Stage 10.

From VINNOVA, KSEK 512 in cash have been received for project SP33 in Stage 10.

In total, KSEK 2 160 + 2 673 + 3 016 + 1 983 + 535 + 2 575 + 100 = KSEK 13 042 have been received from Chalmers for Stage 10. The amounts are shown in Table 1.

In-kind contributions

The in-kind contributions made by Trafikverket and the Industrial Interests Group correspond reasonably well to the agreements for Stage 10, see Table 1. The work performed is briefly presented in the section "Projects and results". The in-kind contributions have been documented on a form from CHARMEC, which the concerned partner has completed and signed. NUTEK's guidelines as of 7 November 1995 were enclosed with the form. Salary costs (number of hours and hourly rates) and other costs (use of machines, materials, and computers, travel expenses, services purchased, etc) are shown on the form. All costs relate to the CHARMEC projects specified in the current report. Parts of the in-kind contributions from Chalmers (totalling KSEK 4 265) originate from the Area of Advance "Transport" (KSEK 3 065) at Chalmers, with support of KSEK 290 to the SP32 project "Sustainable railway asset management", KSEK 2 025 to the SP35 project "Integrated track design for reduced noise effects", KSEK 450 to the SP36 project "Single sensor condition monitoring for noise and deterioration in railway crossings", and KSEK 300 to the SP38 project "Reduced material consumption in railway operations".

Report per programme area

The accounts for each individual project have been allocated funds according to budgets decided by the CHARMEC Board. A compilation by programme area is given in Table 2, which also includes in-kind contributions.

MANAGEMENT AND ADMINISTRATION

Director	Professor Anders Ekberg (from 2012-10-01)
Period	1995-07-01 – 2024-06-30 (2027-06-30)
Chalmers budget (excluding university basic resources)	Stage 1: KSEK 1 084 Stage 2: KSEK 4 000 Stage 3: KSEK 4 400 Stage 4: KSEK 3 900 Stage 5: KSEK 3 900 Stage 6: KSEK 3 700 Stage 7: KSEK 3 900 Stage 8: KSEK 2 900 Stage 9: KSEK 3 543 Stage 10: KSEK 3 000 Stage 11: KSEK 3 000

During Stage 10, Anders Ekberg devoted approximately half of his full-time position to the management and administration of the CHARMEC Competence Centre, Trafikverket's Areas of Excellence and the Shift2Rail and Europe's Rail programmes. The remainder of his time was dedicated to his duties as a teacher, researcher, and research supervisor in Applied Mechanics. From April 2024, he is employed 40% at Trafikverket, see page 77. Docent Björn Pålsson has worked on the management and administration of the Europe's Rail projects and has assisted in the Board meetings. Roger Lundén, Professor of Railway Mechanics and Director of CHARMEC from April 1997 to September 2012, has assisted in the administration of the centre's activities and financing, as well as at Board meetings. Pernilla Appelgren and Jonas Lindqvist from Chalmers Mechanics and Maritime Sciences have assisted with financial issues, see page 86. Professor Jens Nielsen and Bengt Åkesson, Professor Emeritus of Solid Mechanics and first Director of CHARMEC, have assisted in the quality assessment of research reports and administrative documents.

CHARMEC STAGE 11

The Principal Agreement for CHARMEC's Stage 11 (1 July 2024–30 June 2027) largely follows VINNOVA's Principal Agreement for the Centre's Stage 4. As with Stages 5, 6, 7, 8, 9, and 10, Trafikverket (formerly Banverket) has been included in the agreement for Stage 11 and partly assumes the administrative role previously held by VINNOVA. However, since Stage 8, the financial agreements with Trafikverket have been detailed in separate contracts. The rights and obligations of the three parties (Chalmers University of Technology, Trafikverket, and the Industrial Interests Group) essentially comply with those in the Principal Agreements for Stages 4, 5, 6, 7, 8, 9, and 10.

The programme areas in Stage 11 are the same as those during Stage 10, see TS, VB, MU, SD, EU, and SP on page 11.

Since Stage 8, CHARMEC has been involved, through Trafikverket, in the EU Horizon 2020 Joint Technology Initiative Shift2Rail (www.shift2rail.org). Trafikverket was one of the Joint Undertaking (JU) members of Shift2Rail, which had a total budget of MEUR 920. Trafikverket conducted most of its research activities in collaboration with research environments, including CHARMEC. Consequently, Trafikverket's financing was combined with that of Shift2Rail, resulting in an increased total budget for CHARMEC. This greater involvement in EU projects has created new possibilities and challenges for CHARMEC and our partners. For example, during Stages 9 and 10, Anders Ekberg served as the Scientific and Technical co-ordinator for one of the Shift2Rail projects (see EU21 In2Track3 on page 57). Since the end of 2021, the Europe's Rail Joint Undertaking has been established as the successor to Shift2Rail. Trafikverket's research collaboration in Europe's Rail continues in a similar manner as in Shift2Rail. To further support high-quality railway research, Trafikverket established ten Areas of Excellence in 2021 to ensure long-term competence in these areas through research and development, see page 86.

The President of Chalmers University of Technology, Professor Martin Nilsson Jacobi, signed the contract for Stage 11 on 30 August 2024. The funding (kSEK) for Stage 11 (as of 25 November 2024) is shown in the adjoining table. He also appointed the following Board members for CHARMEC's Stage 11 (decision dated 23 May 2024):

Otto Andersson	Trafikverket (chair)
Roger Deuce	Alstom Transportation
Annette Bernström	Green Cargo
Rikard Bolmsvik	Heidelberg Materials
Mikael Rahunen	Lucchini Sweden
Susanne Rymell	SJ
Tilo Reuter	SweMaint
Markus Meinel	SYSTRA Sverige
Melker Pettersson	Trafikverket
Björn Drakenberg	voestalpine Railway Systems
Fredrik Blennow	Wabtec Faiveley Nordic
Sebastian Stichel	KTH Railway Group
Sinisa Krajnovic	Chalmers Mechanics and Maritime Sciences
Violeta Roso	Chalmers Area of Advance Transport

For photos of the new Board, see page 9.

On 23 May 2024, Martin Nilsson Jacobi appointed Anders Ekberg as Director of CHARMEC for Stage 11.

	Cash	In-kind	Total
Industrial Interests Group	9 561	5 199	14 760
Trafikverket (Areas of Exc)	15 000	–	15 000
Chalmers	10 545	1 200	11 745
Chalmers (AoA Transport)	–	2 000	2 000
Europe's Rail	20 973	–	20 973
New Europe's Rail projects	6 000	–	6 000
Trafikverket (projects)	6 998	–	6 998
MISTRA / VINNOVA	2 557	–	2 557
New projects (preliminary)	3 000	–	3 000
From Stage 10	17 688	–	17 688
Total	95 067	8 399	103 466

CONCLUDING REMARKS

Stage 10 of our Competence Centre in Railway Mechanics has been a successful and interesting three year period. The collaboration between the university, industry, and Trafikverket has continued to evolve. National and international research partnerships have increased, particularly our involvement in European projects, which has been our largest ever. I believe CHARMEC has continued to provide first-rate research, act as a knowledgeable dialogue partner, and serve as an important information hub. Stage 10 has once again demonstrated the important role of Railway Mechanics in developing and operating sustainable land transport both in Sweden and internationally. Reliability, environmental, and economic aspects are increasingly being integrated into CHARMEC's research as part of more holistic analyses. In this context, it can be noted that the implementation of CHARMEC's research to address railway issues has provided benefits that far exceed the CHARMEC budget. We look forward to Stage 11 with confidence and will continue to honour our motto "academic excellence combined with industrial relevance".

Gothenburg in June 2025

ANDERS EKBERG

CHARMEC RESEARCH 1995 – 2024 (Status as of January 2025)

TS Interaction of train and track
Programme area 1

TS1 Calculation models of track structures [3]
Prof Thomas Abrahamsson / Doc Jens Nielsen
Mr Johan Oscarsson [2]

TS2 Railhead corrugation formation [3]
Prof Tore Dahlberg [4]
Ms Annika Igeland [2] (now Annika Lundberg)

TS3 Sleeper and railpad dynamics [3]
Prof Tore Dahlberg [4]
Ms Åsa Fenander [2] (now Åsa Sällström)

TS4 Lateral track dynamics [3]
Prof Thomas Abrahamsson / Doc Jens Nielsen
Mr Clas Andersson [2]

TS5 Out-of-round wheels – causes and consequences [3]
Doc Jens Nielsen / Prof Roger Lundén
Mr Anders Johansson [2]

TS6 Identification of dynamic forces in trains [3]
Prof Thomas Abrahamsson / Dr Peter Möller
Mr Lars Nordström [2]

TS7 Dynamics of track switches [3]
Prof Jens Nielsen / Prof Tore Dahlberg [4]
Mr Elias Kassa [2]

TS8 Integrated track dynamics
Prof Jens Nielsen

TS9 Track dynamics and sleepers [3]
Prof Thomas Abrahamsson / Prof Jens Nielsen
Ms Johanna Lilja [1]

TS10 Track response when using Under Sleeper Pads (USP) [3]
Dr Rikard Bolmsvik / Prof Jens Nielsen

TS11 Rail corrugation growth on curves [3]
Prof Jens Nielsen / Dr Anders Frid
Mr Peter Torstensson [2]

TS12 Identification of wheel–rail contact forces [3]
Doc Fredrik Larsson / Dr Håkan Johansson / Prof Kenneth Runesson / Dr Peter Möller / Prof Jens Nielsen
Mr Hamed Ronasi [2]

TS13 Optimization of track switches [3]
Prof Jens Nielsen / Prof Thomas Abrahamsson
Mr Björn Pålsson [2]

TS14 Multicriterion optimization of track properties [3]
Prof Thomas Abrahamsson / Prof Jens Nielsen
Mr Sadegh Rahrovani [2]

TS15 Improved availability and reduced life cycle cost of track switches [3]
Prof Jens Nielsen / Prof Magnus Ekh / Prof Elena Kabo / Dr Peter Torstensson
Ms Xin Li [2]

TS16 Time-domain model of railway braking noise [3]
Dr Peter Torstensson

TS17 Optimization of materials in track switches [3]
Prof Jens Nielsen / Prof Magnus Ekh / Doc Björn Pålsson
Mr Rostyslav Skrypnyk [2]

TS18 Numerical simulations of train-track deterioration
Doc Björn Pålsson

TS19 Design criteria for slab track structures [3]
Prof Jens Nielsen / Dr Rikard Bolmsvik / Prof Anders Ekberg
Mr Emil Aggestam [2]

TS20 Wheel tread damage – identification and effects [3]
Prof Elena Kabo / Prof Anders Ekberg / Prof Jens Nielsen / Doc Tore Vernersson
Mr Michele Maglio [2]

TS21 Model-based condition monitoring of S&C [3]
Doc Björn Pålsson / Prof Jens Nielsen / Prof Håkan Johansson
Mr Marko Milosevic [2]

TS22 Transition zone design for reduced track settlements
Prof Jens Nielsen / Prof Magnus Ekh / Prof Jelke Dijkstra
Mr Kourosh Nasrollahi [1]

TS23 Optimization of crossing panel design for improved long-term performance
Prof Jens Nielsen / Doc Björn Pålsson
Mr Henrik Vilhelmson [1]

TS24 Risk analysis for derailment in switches
Doc Björn Pålsson / Prof Elena Kabo / Prof Anders Ekberg / Dr Björn Paulsson
Mr Sucheth Bysani [1]

TS25 Digital twins for efficient maintenance of switches & crossings
Doc Björn Pålsson / Dr Peter Torstensson / Dr Kristofer Odolinski
Mr Karl Norberg

VB Vibrations and noise
Programme area 2

VB1 Structural vibrations from railway traffic [3]
Prof Sven Ohlsson / Prof Thomas Abrahamsson
Mr Johan Jonsson [2]

VB2 Noise from tread braked railway vehicles [3]
Prof Roger Lundén / Dr Peter Möller
Mr Tore Vernersson [2] / Mr Martin Petersson [1]

VB3 Test rig for railway noise [3]
Prof Roger Lundén
Mr Tore Vernersson [2]

VB4 Vibrations and external noise from train and track [3]
Prof Roger Lundén / Dr Anders Frid / Doc Jens Nielsen
Mr Carl Fredrik Hartung [1]

VB5 Wave propagation under high-speed trains [3]
Prof Nils-Erik Wiberg
Mr Torbjörn Ekevid [2]

VB6 Interaction of train, soil and buildings [3]
Dr Johan Jonsson

VB7 Vibration transmission in railway vehicles [3]
Prof Thomas Abrahamsson / Prof Tomas McKelvey
Mr Per Sjövall [2]

VB8 Ground vibrations from railways [3]
Prof Anders Boström / Prof Thomas Abrahamsson
Mr Anders Karlström [2]

VB9 Dynamics of railway systems [3]
Prof Nils-Erik Wiberg / Dr Torbjörn Ekevid
Mr Håkan Lane [2]

VB10 External noise generation from trains [3]
Prof Wolfgang Kropp
Ms Astrid Pieringer [2]

VB11 Abatement of curve squeal noise from trains [3]
Prof Wolfgang Kropp / Dr Astrid Pieringer
Mr Ivan Zenzerovic [2]

VB12 High-frequency wheel–rail interaction
Doc Astrid Pieringer / Dr Jannik Theyssen

VB13 Prediction and mitigation of noise from vehicles on slab tracks [3]
Prof Wolfgang Kropp / Dr Astrid Pieringer
Mr Jannik Theyssen [2]

Departments involved at Chalmers:
Architecture and Civil Engineering, ACE
Industrial and Materials Science, IMS
Mechanics and Maritime Sciences, M2

Upper name(s):
Project leader(s) and supervisor(s)

Lower name:
Doctoral candidate

MU Materials and maintenance
Programme area 3

MU1 Mechanical properties of ballast [3]
Prof Kenneth Runesson
Mr Lars Jacobsson [1]

MU2 New materials in wheels and rails [3]
Prof Birger Karlsson
Mr Johan Ahlström [2]

MU3 Martensite formation and damage around railway wheel flats [3]
Prof Roger Lundén
Mr Johan Jergéus [2]

MU4 Prediction of lifetime of railway wheels [3]
Prof Roger Lundén
Mr Anders Ekberg [2]

MU5 Mechanical properties of concrete sleepers [3]
Prof Kent Gylltoft
Mr Rikard Gustavson [2] *(now Rikard Bolmsvik)*

MU6 Rolling contact fatigue of rails [3]
Prof Lennart Josefson
Mr Jonas Ringsberg [2]

MU7 Laser treatment of wheels and rails [3]
Prof Birger Karlsson
Mr Simon Niederhauser [2]

MU8 Butt-welding of rails [3]
Prof Lennart Josefson / Doc Jonas Ringsberg
Mr Anders Skyttebol [2]

MU9 Rolling contact fatigue of railway wheels [3]
Doc Anders Ekberg / Dr Elena Kabo / Prof Roger Lundén

MU10 Crack propagation in railway wheels [3]
Prof Hans Andersson / Dr Elena Kabo / Doc Anders Ekberg
Ms Eka Lansler [1]

MU11 Early crack growth in rails [3]
Prof Lennart Josefson / Doc Jonas Ringsberg / Prof Kenneth Runesson
Mr Anders Bergkvist [1]

MU12 Contact and crack mechanics for rails [3]
Prof Peter Hansbo
Mr Per Heintz [2]

MU13 Wheel and rail materials at low temperatures [3]
Dr Johan Ahlström / Prof Birger Karlsson

MU14 Damage in track switches [3]
Doc Magnus Ekh / Prof Kenneth Runesson
Mr Göran Johansson [2]

MU15 Microstructural development during laser coating [3]
Prof Birger Karlsson / Dr Johan Ahlström

MU16 Alternative materials for wheels and rails [3]
Dr Johan Ahlström / Prof Birger Karlsson
Mr Niklas Köppen [1]

MU17 Elastoplastic crack propagation in rails [3]
Doc Fredrik Larsson / Prof Kenneth Runesson / Prof Lennart Josefson
Mr Johan Tillberg [2]

MU18 Wheels and rails at high speeds and axle loads [3]
Doc Anders Ekberg / Prof Lennart Josefson / Prof Kenneth Runesson / Prof Jacques de Maré
Mr Johan Sandström [2]

MU19 Material anisotropy and RCF [5] **of rails and switches** [3]
Prof Magnus Ekh / Prof Kenneth Runesson / Doc Anders Ekberg
Ms Nasim Larijani [2]

MU20 Wear impact on RCF [5] **of rails** [3]
Prof Magnus Ekh / Doc Fredrik Larsson / Doc Anders Ekberg
Mr Jim Brouzoulis [2]

MU21 Thermal impact on RCF [5] **of wheels** [3]
Doc Anders Ekberg / Doc Elena Kabo / Prof Magnus Ekh / Dr Tore Vernersson
Ms Sara Caprioli [2]

MU22 Improved criterion for surface initiated RCF [5]
Prof Anders Ekberg / Prof Elena Kabo / Prof Roger Lundén

MU23 Material behaviour at rapid thermal processes [3]
Doc Johan Ahlström / Prof Christer Persson
Mr Krste Cvetkovski [2]

MU24 High-strength steels for railway rails [3]
Prof Christer Persson / Prof Magnus Ekh
Mr Martin Schilke [2]

MU25 Thermodynamically coupled contact between wheel and rail [3]
Doc Anders Ekberg / Doc Fredrik Larsson / Prof Kenneth Runesson
Mr Andreas Draganis [2]

MU26 Optimum inspection and maintenance of rails and wheels [3]
Doc Ann-Brith Strömberg / Doc Anders Ekberg / Prof Michael Patriksson
Mr Emil Gustavsson [2]

MU27 Progressive degradation of rails and wheels [3]
Doc Elena Kabo / Doc Anders Ekberg / Prof Michael Patriksson
Mr Kalle Karttunen [2]

MU28 Mechanical performance of wheel and rail materials [3]
Prof Johan Ahlström / Prof Christer Persson / Prof Magnus Ekh
Mr Dimitrios Nikas [2]

MU29 Damage in wheel and rail materials [3]
Prof Johan Ahlström / Prof Christer Persson
Ms Casey Jessop [2]

MU30 Modelling of properties and damage in wheel and rail materials
Prof Johan Ahlström

MU31 Squats in rails and RCF [5] **clusters on wheels** [3]
Prof Elena Kabo / Prof Fredrik Larsson / Prof Anders Ekberg / Dr Peter Torstensson
Mr Robin Andersson [2]

MU32 Modelling of thermomechanically loaded rail and wheel steels [3]
Prof Magnus Ekh / Prof Johan Ahlström / Doc Tore Vernersson
Mr Ali Esmaeili [2]

MU33 Numerical simulation of rolling contact fatigue crack growth in rails [3]
Prof Fredrik Larsson / Prof Anders Ekberg
Mr Dimosthenis Floros [2]

MU34 Influence of anisotropy on deterioration of rail materials [3]
Prof Magnus Ekh / Prof Johan Ahlström
Mr Knut Andreas Meyer [2]

Notes:
1. Licentiate (*teknologie licentiat*)
2. PhD (*teknologie doktor*)
3. This project has been concluded
4. Later at Linköping Institute of Technology
5. Rolling Contact Fatigue

The abbreviation ***Doc*** is used for ***Docent***, which is the highest academic qualification in Sweden (above the doctor's level)

MU (cont'd)

MU35 – **Characterization of crack initiation and propagation in anisotropic material** 3
Prof Johan Ahlström / Prof Magnus Ekh
Mr Daniel Gren 2

MU36 – **Material characteristics in welding and other local heating events** 3
Prof Johan Ahlström / Prof Magnus Ekh
Ms Erika Steyn 2

MU37 – **Numerical simulations of welding and other high-temperature processes** 3
Prof Magnus Ekh / Prof Johan Ahlström / Prof Lennart Josefson
Mr Björn Andersson 2

MU38 – **Growth of rolling contact fatigue cracks** 3
Prof Fredrik Larsson / Prof Anders Ekberg / Prof Elena Kabo
Mr Mohammad Salahi Nezhad 2

MU39 – **Numerical modelling of material deterioration in railway applications**
Prof Magnus Ekh / Prof Fredrik Larsson

MU40 – **Digital twins of reprofiled rails**
Prof Fredrik Larsson / Prof Magnus Ekh / Prof Ragnar Larsson / Doc Björn Pålsson
Ms Caroline Ansin 1

MU41 – **Crack initiation in anisotropic wheel / rail material**
Prof Magnus Ekh / Prof Johan Ahlström / Dr Knut Andreas Meyer
Ms Nasrin Talebi 1

SD Systems for monitoring & operation
Programme area 4

SD1 – **Braking of freight trains – a systems approach** 3
Prof Göran Gerbert
Mr Daniel Thuresson 2

SD2 – **Sonar pulses for braking control** 3
Prof Bengt Schmidtbauer / Mr Hans Sandholt

SD3 – **Computer control of braking systems for freight trains** 3
Mr Håkan Edler / Prof Jan Torin
Mr Roger Johansson 2

SD4 – **Control of block braking** 3
Prof Roger Lundén
Mr Tore Vernersson 2

SD5 – **Active and semi-active systems in railway vehicles** 3
Prof Jonas Sjöberg / Prof Thomas Abrahamsson
Ms Jessica Fagerlund 1

SD6 – **Adaptronics for bogies and other railway components** 3
Prof Viktor Berbyuk / Doc Mikael Enelund
Mr Albin Johnsson 1

SD7 – **Thermal capacity of tread braked railway wheels** 3
Prof Roger Lundén / Dr Tore Vernersson
Mr Shahab Teimourimanesh 2

SD8 – **Wear of disc brakes and block brakes** 3
Dr Tore Vernersson / Prof Roger Lundén

SD9 – **Multiobjective optimization of bogie system and vibration control** 3
Prof Viktor Berbyuk / Prof Mikael Enelund
Mr Milad Mousavi 2

SD10 – **Enhanced mechanical braking systems for modern trains** 3
Doc Tore Vernersson / Prof Roger Lundén
Mr Mandeep Singh Walia 2

SD11 – **Tread braking – capacity, wear and life** 3
Doc Tore Vernersson / Prof Roger Lundén
Mr Eric Voortman Landström 2

SD12 – **Holistic simulations of wheel tread life based on field and rig testing**
Doc Tore Vernersson / Prof Roger Lundén / Doc Björn Pålsson
Mr Matheus de Lara Todt

EU Parallel EU projects
Programme area 5

EU1 – **EuroSABOT** 3
Prof Roger Lundén
Mr Tore Vernersson / Mr Martin Petersson

EU2 – **Silent Freight** 3
Dr Jens Nielsen
Mr Martin Petersson / Mr Markus Wallentin

EU3 – **Silent Track** 3
Dr Jens Nielsen
Mr Clas Andersson

EU4 – **ICON** 3
Prof Lennart Josefson
Mr Jonas Ringsberg

EU5 – **EuroBALT II** 3
Prof Tore Dahlberg 4
Mr Johan Oscarsson

EU6 – **HIPERWHEEL** 3
Prof Roger Lundén
Doc Jens Nielsen / Dr Anders Ekberg

EU7 – **INFRASTAR** 3
Prof Lennart Josefson / Prof Roger Lundén / Doc Jens Nielsen / Dr Jonas Ringsberg / Prof Birger Karlsson

EU8 – **ERS** 3
Prof Roger Lundén
Mr Martin Helgen / Doc Jan Henrik Sällström / Mr Tore Vernersson

EU9 – **EURNEX** 3
Prof Roger Lundén / Doc Anders Ekberg

EU10 – **INNOTRACK** 3
Prof Roger Lundén / Doc Anders Ekberg and co-workers

EU11 – **QCITY** 3
Prof Jens Nielsen

EU12 – **RIVAS** 3
Prof Jens Nielsen and co-workers

EU13 – **D-RAIL** 3
Doc Anders Ekberg and co-workers

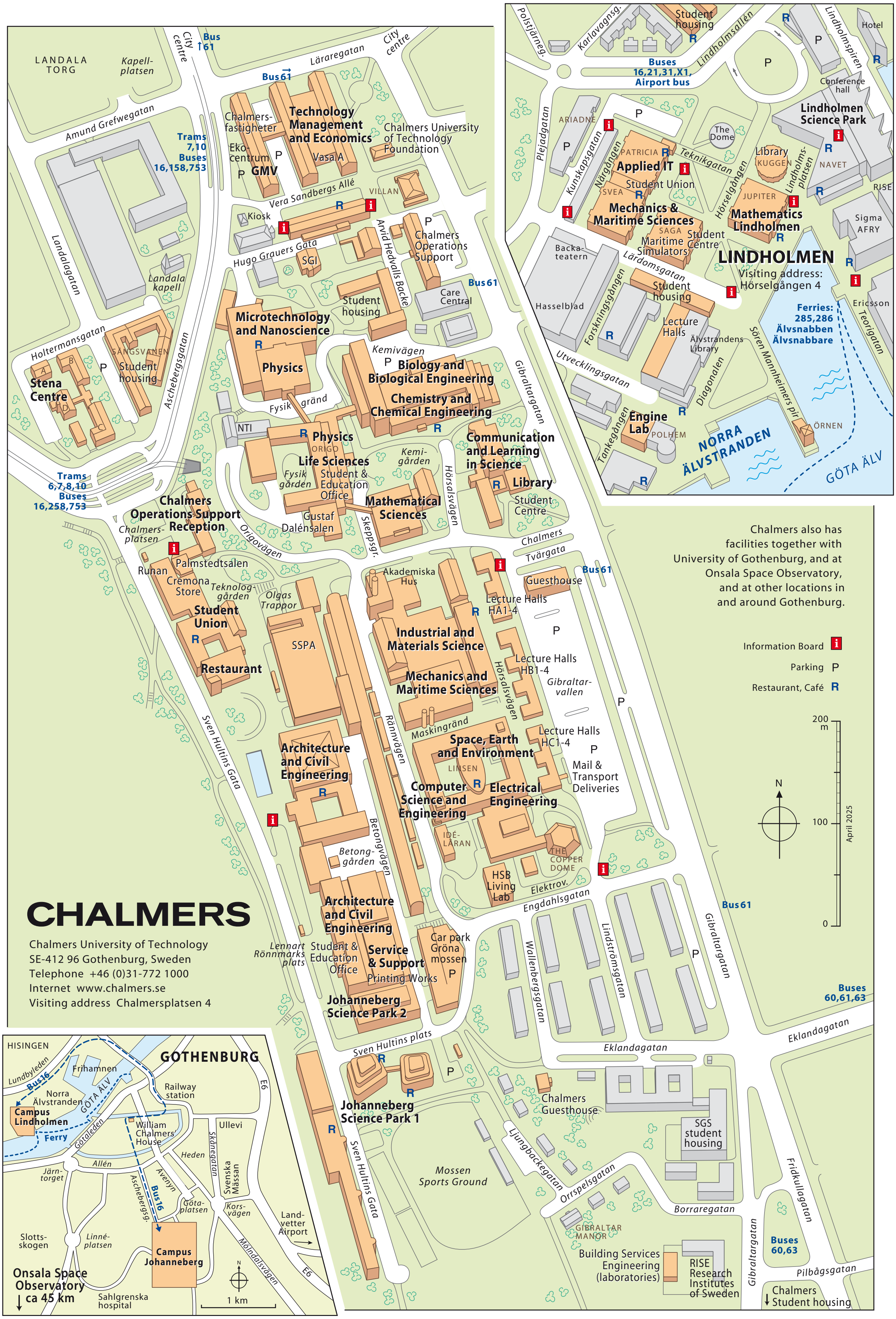
EU14 – **Capacity4Rail** 3
Prof Anders Ekberg and co-workers

EU (cont'd)

EU15	**WRIST** [3] *Prof Lennart Josefson / Dr Jim Brouzoulis*
EU16	**In2Rail** [3] *Prof Anders Ekberg and co-workers*
EU17	**In2Track** [3] *Prof Anders Ekberg and co-workers*
EU18	**Fr8Rail** [3] *Prof Anders Ekberg / Doc Tore Vernersson*
EU19	**In2Track2** [3] *Prof Anders Ekberg and co-workers*
EU20	**Fr8Rail2** [3] *Prof Anders Ekberg / Doc Tore Vernersson*
EU21	**In2Track3** [3] *Prof Anders Ekberg and co-workers*
EU22	**R2DATO** *Doc Björn Pålsson / Doc Tore Vernersson / Prof Elena Kabo*
EU23	**IAM4RAIL** *Prof Anders Ekberg and co-workers*
EU24	**RAIL4EARTH** *Prof Jens Nielsen / Doc Astrid Pieringer*
EU25	**TRANS4M-R** *Doc Björn Pålsson / Doc Tore Vernersson / Prof Jens Nielsen*
EU26	**FUTURE** *Doc Tore Vernersson*
EU27	**IAM4RAIL – Condition monitoring for high-speed turnouts** *Doc Björn Pålsson / Dr Jannik Theyssen / Doc Astrid Pieringer / Dr Eric Voortman Landström*

SP Parallel special projects
Programme area 6

SP1	Lucchini Sweden AB (bilateral agreement)
SP2	Noise from Swedish railways
SP3	Track force measurements on X2
SP4	VAE AG (bilateral agreement)
SP5	voestalpine Schienen GmbH (bilateral agreement)
SP6	Development of a quiet rail
SP7	Lateral track stability
SP8	Design of insulated joints
SP9	Sleeper design for 30 tonne axle load
SP10	Noise reduction measures and EU project QCITY
SP11	Vertical contact forces of high-speed trains
SP12	New sleeper specifications
SP13	Alarm limits for wheel damage
SP14	Particle emissions and noise from railways
SP15	Computer program for design of block brakes
SP16	Dynamic properties of timber sleepers and concrete replacement sleepers
SP17	Switch sleeper specifications
SP18	Ground vibrations – influence of vehicle parameters
SP19	Optimum track stiffness
SP20	Classification of wheel damage forms
SP21	Optimum material selection for track switches
SP22	Implementing INNOTRACK results at Trafikverket
SP23	Optimized prestressed concrete sleeper
SP24	Derailment risks in switches
SP25	Harmonized measurement sites for track forces
SP26	Holistic optimization of tracks
SP27	Optimized prestressed concrete sleeper – phase II
SP28	Prevention and mitigation of derailments
SP29	Including wear caused by braking in train driving simulators
SP30	Railway vehicle risk analyses
SP31	Intelligent railway digitalization
SP32	Sustainable railway asset management
SP33	More robust switches through improved control of the switch rail
SP34	Full-scale brake test rig
SP35	Integrated track design for reduced noise effects
SP36	Single sensor condition monitoring for noise and deterioration in railway crossings
SP37	Improved regulations and procedures for damaged wheels
SP38	Reduced material consumption in railway operations



CHALMERS

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Chalmers also has facilities together with University of Gothenburg, and at Onsala Space Observatory, and at other locations in and around Gothenburg.

CHALMERS UNIVERSITY OF TECHNOLOGY 2025

Departments and research groups / divisions / areas

ARCHITECTURE AND CIVIL ENGINEERING
Applied Acoustics
Architectural Theory and Methods
Building Design
Building Services Engineering
Building Technology
Construction Management and Engineering
Geology and Geotechnics
Structural Engineering
Sustainable Urban Water and Environmental Engineering
Urban Design and Planning
Water Environment Technology

CHEMISTRY AND CHEMICAL ENGINEERING
Applied Chemistry
Chemical Engineering
Chemistry and Biochemistry
Energy and Materials

COMMUNICATION AND LEARNING IN SCIENCE
Engineering Education Research
Information Resources and Scientific Publishing
Language and Communication
Learning and Learning Environments

COMPUTER SCIENCE AND ENGINEERING
Computer and Network Systems
Computing Science
Data Science and AI
Interaction Design and Software Engineering

ELECTRICAL ENGINEERING
Communications, Antennas, and Optical Networks
Electric Power Engineering
Signal Processing and Biomedical Engineering
Systems and Control

INDUSTRIAL AND MATERIALS SCIENCE
Design & Human Factors
Engineering Materials
Material and Computational Mechanics
Materials and Manufacture
Product Development
Production Systems

LIFE SCIENCES
Chemical Biology
Food and Nutrition Science
Industrial Biotechnology
Infrastructures
Systems and Synthetic Biology

MATHEMATICAL SCIENCES
Algebra and Geometry
Analysis and Probability Theory
Applied Mathematics and Statistics

MECHANICS AND MARITIME SCIENCES
Dynamics
Fluid Dynamics
Marine Technology
Maritime Studies
Transport, Energy and Environment
Vehicle Engineering and Autonomous Systems (VEAS)
Vehicle Safety

MICROTECHNOLOGY AND NANOSCIENCE
Applied Quantum Physics
Electronics Materials and Systems
Microwave Electronics
Nanofabrication
Photonics
Quantum Device Physics
Quantum Technology
Terahertz and Millimetre Wave

PHYSICS
Chemical Physics
Condensed Matter and Materials Theory
Materials Physics
Microstructure Physics
Nano and Biophysics
Subatomic, High Energy and Plasma Physics

SPACE, EARTH AND ENVIRONMENT
Astronomy and Plasma Physics
Energy Technology
Geoscience and Remote Sensing
Onsala Space Observatory
Physical Resource Theory

TECHNOLOGY MANAGEMENT AND ECONOMICS
Entrepreneurship and Strategy
Environmental Systems Analysis
Innovation and R&D Management
Science, Technology and Society
Supply and Operations Management

Research centres

In total 33 centres in the following areas:

- Built Environment *(2 centres)*
- Energy *(5 centres)*
- Graphene and other 2d-materials *(2 centres)*
- Health Engineering *(1 centre)*
- Information and Communication Technology *(5 centres)*
- Materials Science *(3 centres)*
- Production *(6 centres)*
- Transport *(5 centres)*
- Quantum Technology *(1 centre)*
- Sustainable Development *(3 centres)*

Educational programmes

PREPARATORY EDUCATION
Summer courses
Engineering preparatory year

BACHELOR'S STUDIES *(mainly in Swedish)*
2 bachelor's programmes
8 bachelor's in engineering programmes

MARINE AND NAUTICAL STUDIES
4 programmes *(mainly in Swedish)*

ARCHITECTURE AND MASTERS OF ENGINEERING PROGRAMMES
(5 years combined BSc and MSc)
17 programmes *(BSc mainly in Swedish)*

MASTER'S STUDIES
Architecture
Automation and Mechatronics
Biotechnology and Chemical Engineering
Civil Engineering
Computer Engineering
Electrical Engineering
Industrial Engineering and Management
Information Engineering
Maritime Management
Mechanical and Industrial Design Engineering
Physics, Mathematics and Environment
Technology and Learning

MASTER'S PROGRAMMES
38 international programmes *(in English)*
1 teacher's programme:
Learning and leadership *(in Swedish)*

LICENTIATE AND PHD PROGRAMMES
27 graduate schools, each organised within a department or common to a number of departments and with a corresponding research

CONTINUING PROFESSIONAL DEVELOPMENT
Contract education
Courses from the ordinary range of education
Open online courses

Areas of Advance

Chalmers has profiled its research activities around seven Areas of Advance *(Swedish: Styrkeområden)*. CHARMEC is presently active in the area Transport

Energy
Health Engineering
Information and Communication Technology
Materials Science
Nano
Production
Transport

29 years
60 doctors of engineering
725 international publications

CHARMEC

Chalmers

CHARMEC

Railway

CHARMEC

Mechanics

CHARMEC

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