



# Monitoring during revenue operations for condition based maintenance: the case of ABA measurements in the Netherlands

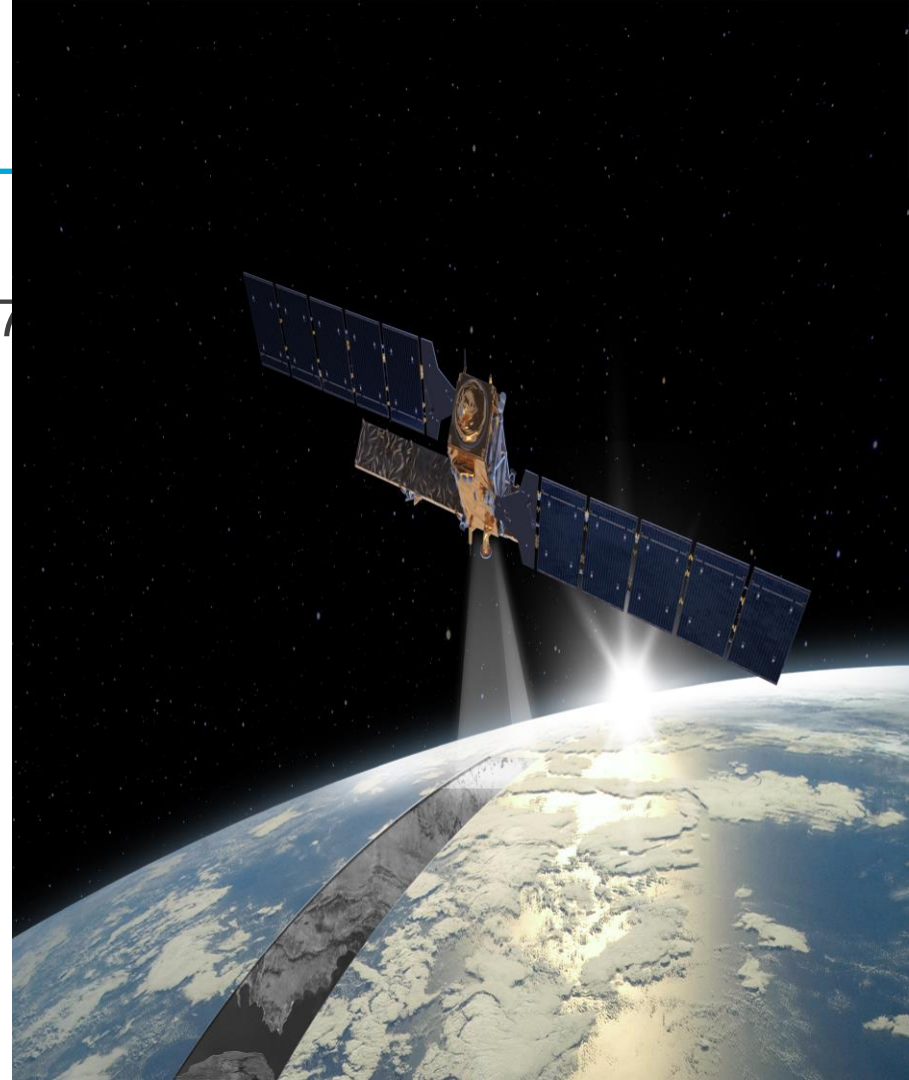
*Rolf Dollevoet*

Prof.dr.ir. R.P.B.J. Dollevoet | 28<sup>th</sup> of August 2017

# Contents

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- Railway Engineering Group
- Education / MOOC October 2017
- Research / monitoring
- Cases Intelliswitch
  - CTO train
  - Axlebox accelerations (ABA)
  - Remote sensing



# Group: Railway Engineering, TU Delft

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## **1949 – 2006 chair:**

Van Veen, Cuperus, Van Bilderbeek, Van Witsen, **Esveld**

## **2006 – 2012:**

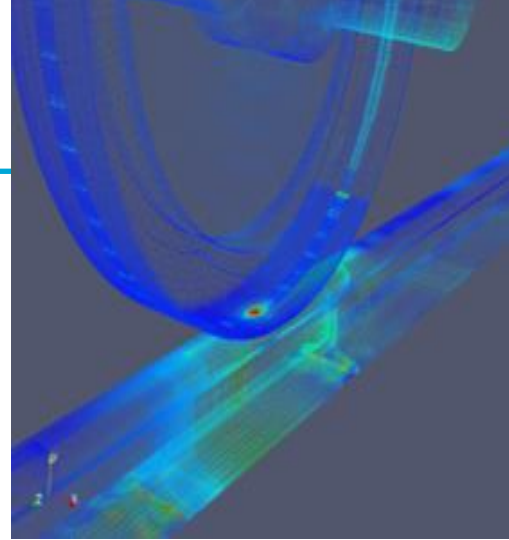
Chair vacancy....

## **2012 > chair:**

Dollevoet (part-time TU Delft and ProRail (Dutch infra manager Railway))

Challenge and focus: **more for less** money, and **interfaces** research

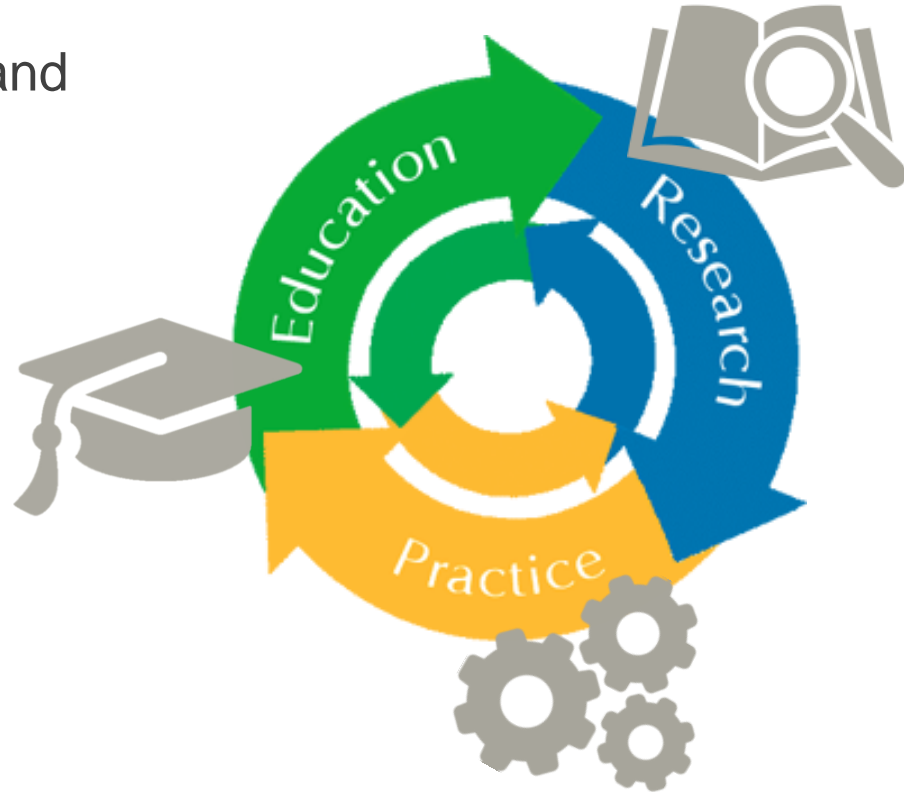
**Group:** *13 staff members, 18 PhD's, 1 PDEng, 4 Postdoc's,  
6 guest researchers*



# Education: knowledge for craftsmanship

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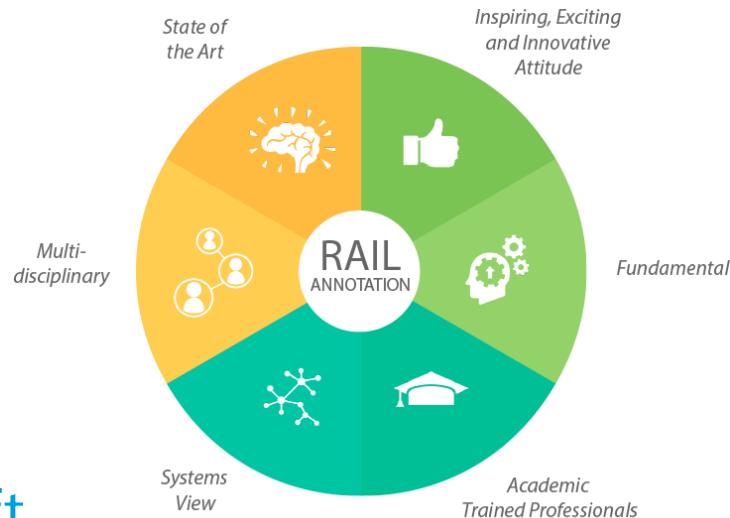
- Academic research
- Practical validation and experience
- Adult education





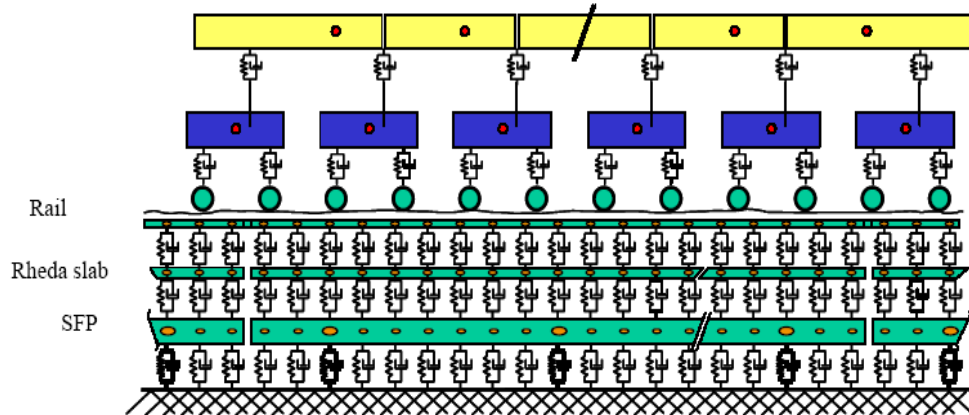
# New talents at MSc-level

- Attract young students (BSc)
- 11 new blended courses
- Specialisation Railway Systems



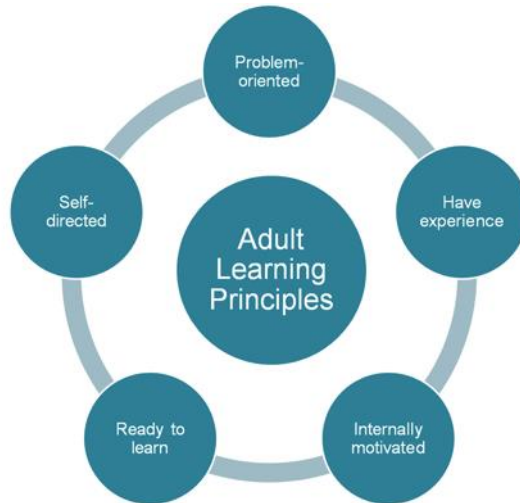
# Professional Doctorate PDEng

- Pure focus on innovation
- From talent to specialist in 2 years
- Practical themes of Rail practice



# Professional Education

- Long life learning
- Modular program, part-time
- Actual issues to be engineered





# Worldwide on demand

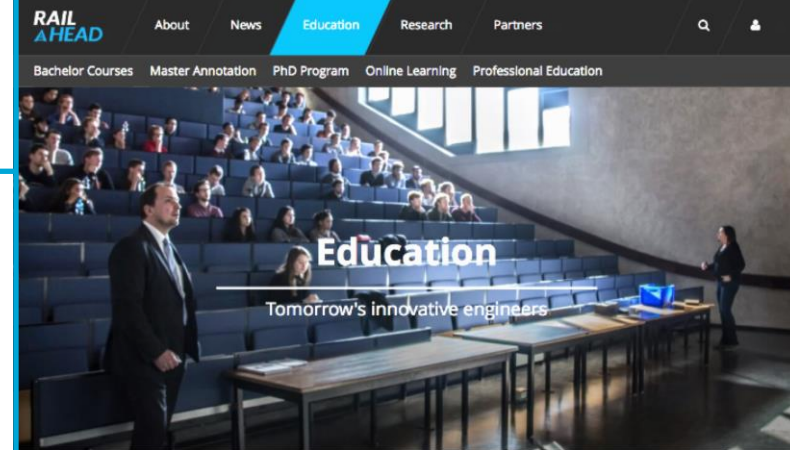
- New online courses, MOOC Rail
- Focus on System approach
- Starts in October 2017





# Online platform RailaHead

- Enthuse students early
- Knowledge centre
- International connections



## Bachelor Courses

### Why study Railway Engineering?

Railways are complex systems that combine various multidisciplinary aspects such as infrastructure, operations, management, safety and policy. It is the fastest and most reliable way of transportation and used by more people worldwide than any other way of public transport. Keeping the system up and running brings many challenges everyday and to stay ahead on the changing demands of passengers asks for innovation and a long term vision.

The railway infrastructure (track, power supply, rolling stock, safety and signalling) should facilitate the desired railway operations (train services, traffic density, heterogeneity, synchronisation, speed) based on the transportation requirements. Therefore railway engineers should have an integrated knowledge on the whole system and interactions between subsystems.

#### Bachelor Courses

To get acquainted with the complex nature of the railway systems two courses are offered in TU Delft: Bachelor Program; Minor Bend and Break and Introductory course Road and Railway (B3320). Students can also choose to write their Bachelor Thesis on rail related topics, supported by our academic staff and people from the railway sector.

#### Get information

Stop by our department on Wednesday or Thursday and our staff will be available to answer your questions on the different courses, how to integrate them within your curriculum and possibilities to study Rail within the Master.

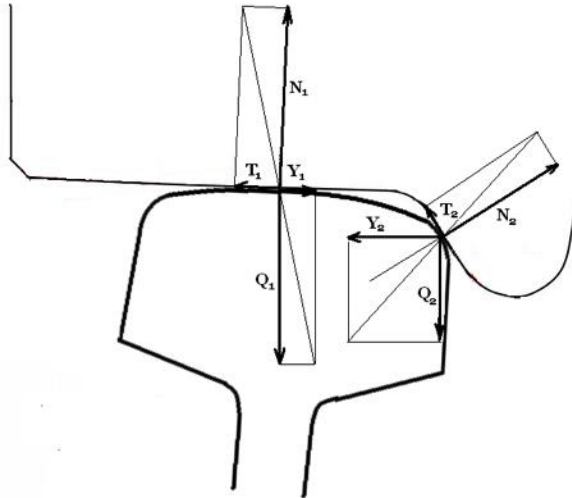
For more information contact: **Stevin II building** (room S2 2.33) or by absence **Jacqueline Barnhoorn** (room S2 2.29)



Minor Bend and Break (2015, 2016)

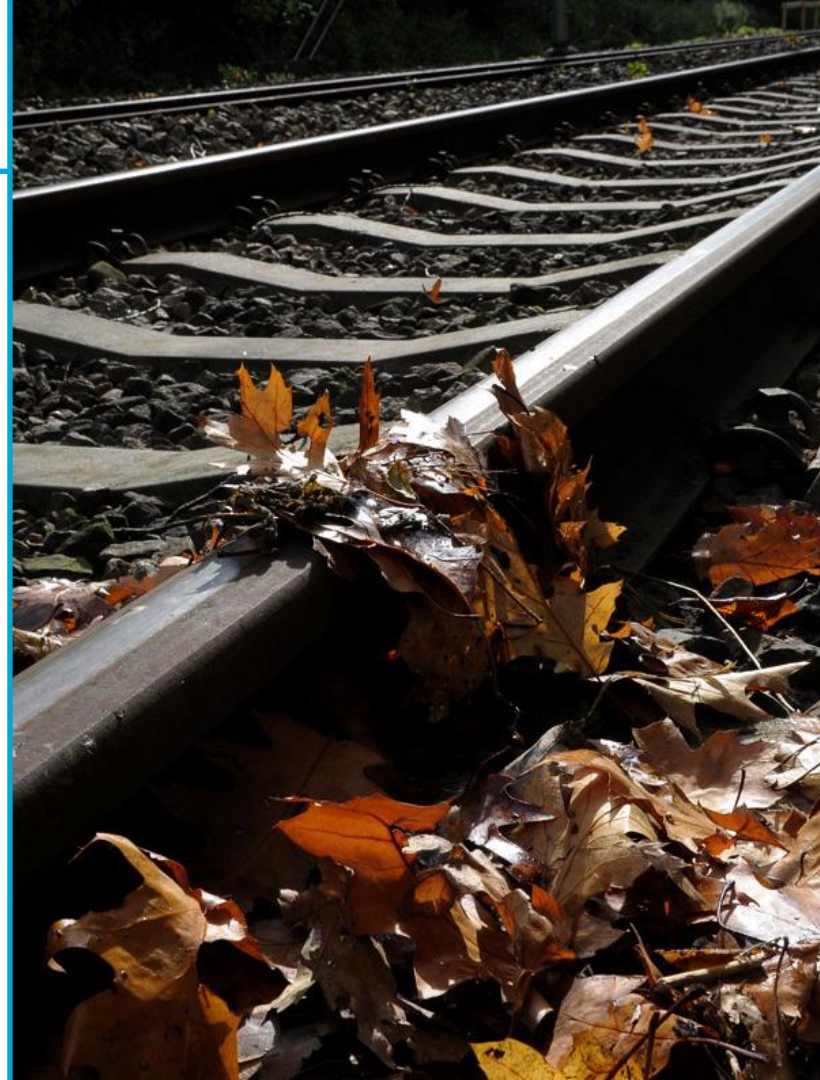
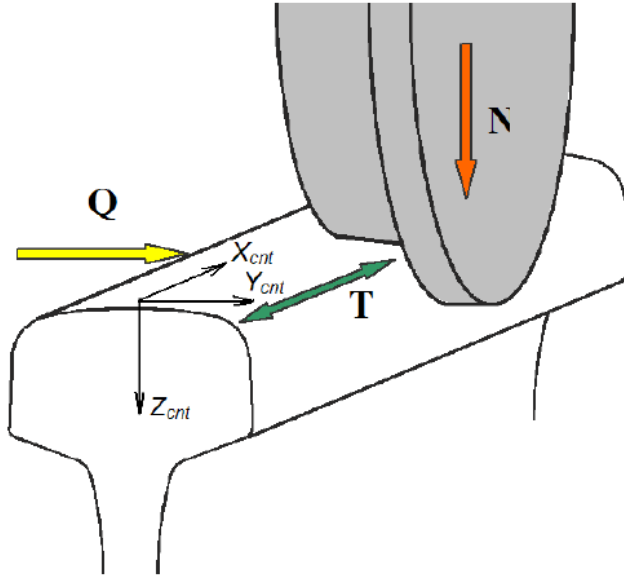
# Research: real-life-lab

- CTO measurements
- Modeling
- Wheel-rail test rig



# Wheel-Rail Contact

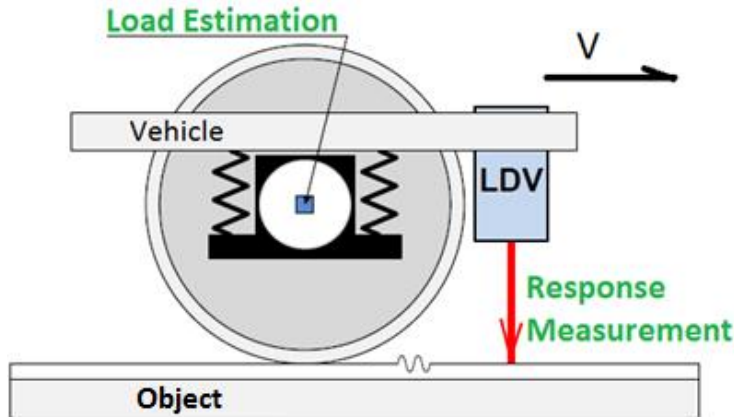
- Slippery track
- Noise and vibration issues
- Preventive maintenance





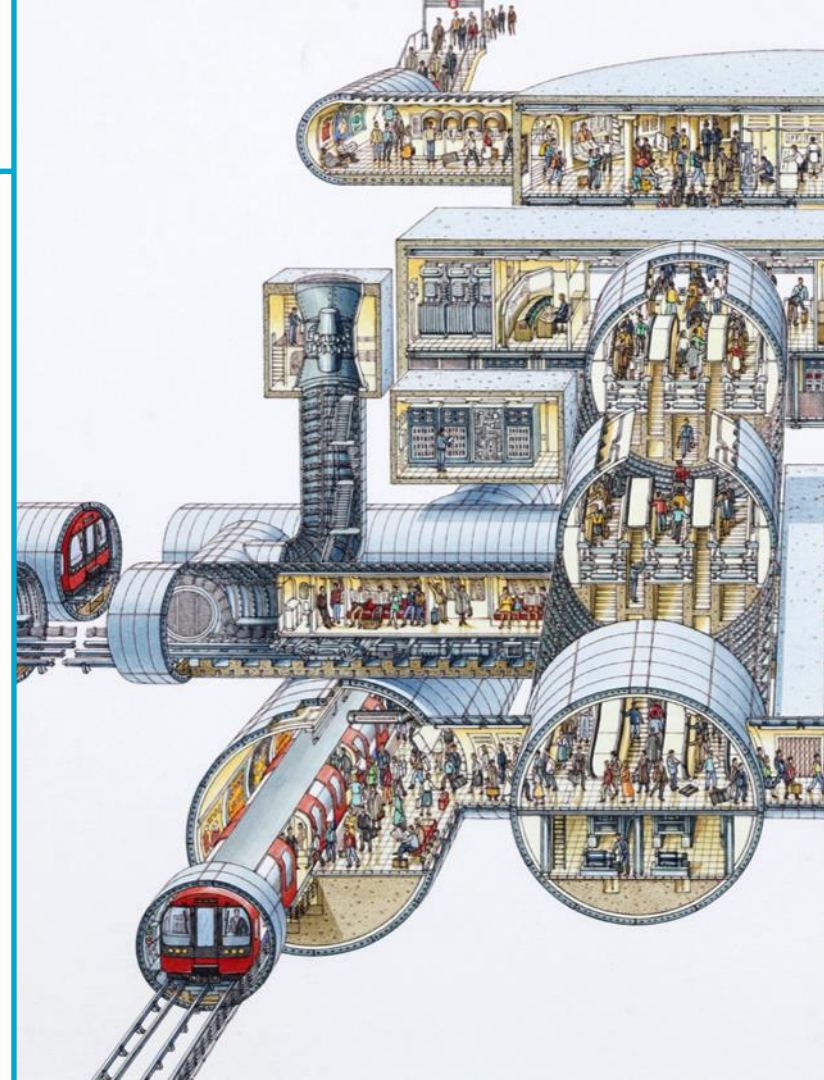
# Sensors / Monitoring

- Measurements on board
- Predictive maintenance
- Vehicle behaviour / Big data



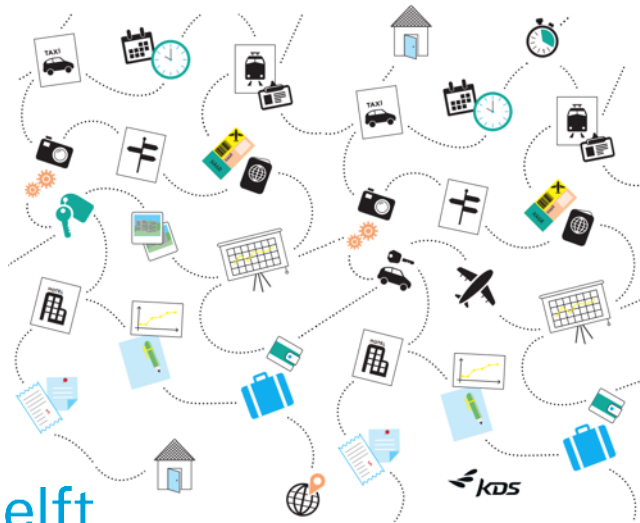
# Operations and design

- 'Choice' vision
- Less switches and level crossings
- Robust System



# Door to Door

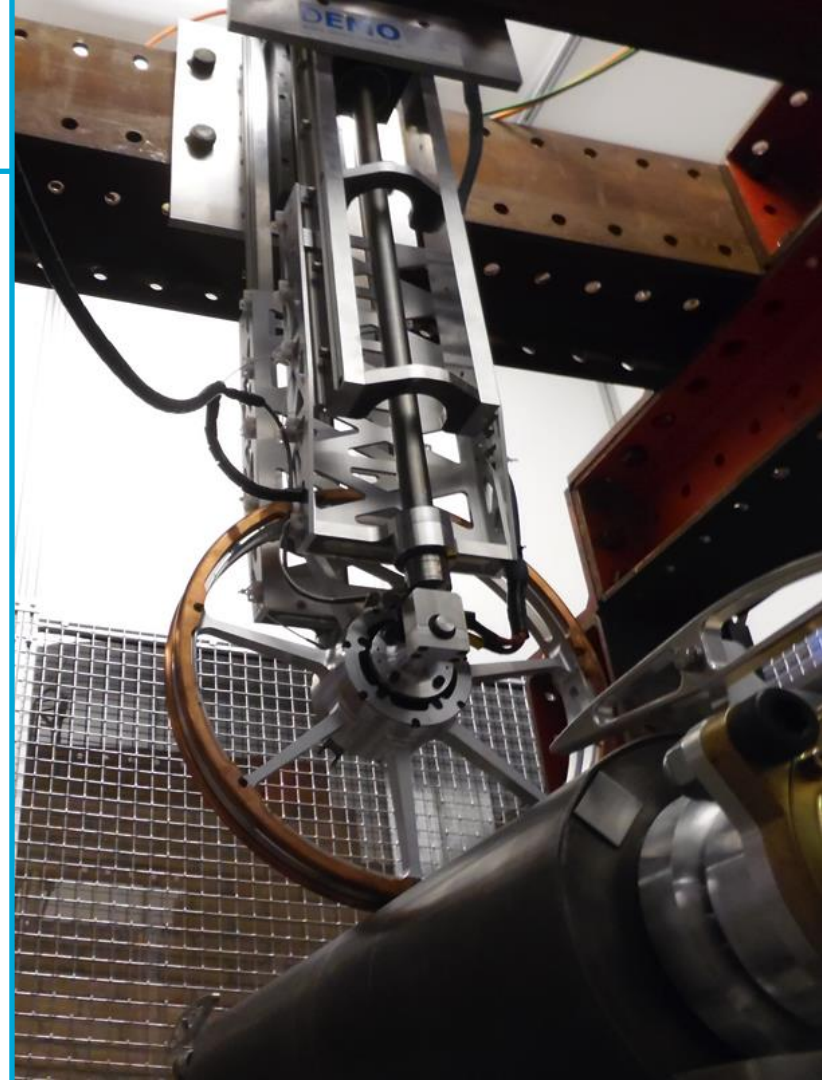
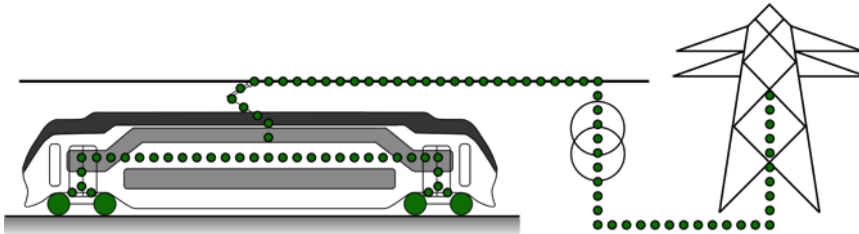
- Twizy D2D100%EV
- Passenger Journey
- Station of the Future (Delft Zuid)





# Energy

- Rolling pantograph
- Recuperation brake energy
- 3kVolts project, the Netherlands



# Crowd Sensing

- Social Awareness
- Rush hour questions
- Sensors = passenger



# Virtual Reality

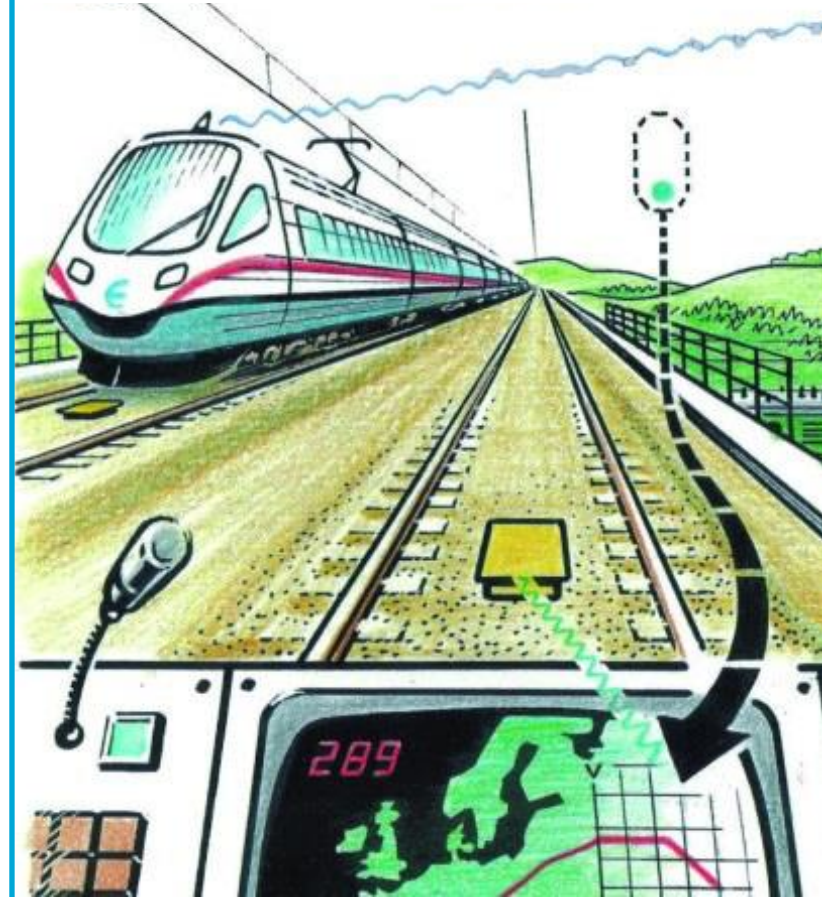
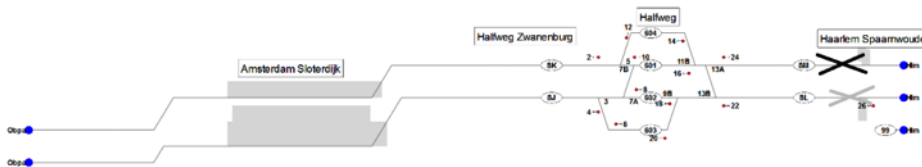
- Serious Gaming
- Education and training
- Costs efficient; easy plan process





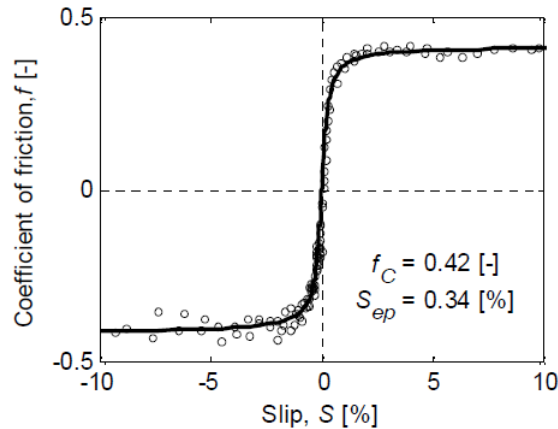
# Operations Control

- ERTMS
- ATO (automatic train operation)
- Monitoring platform = train



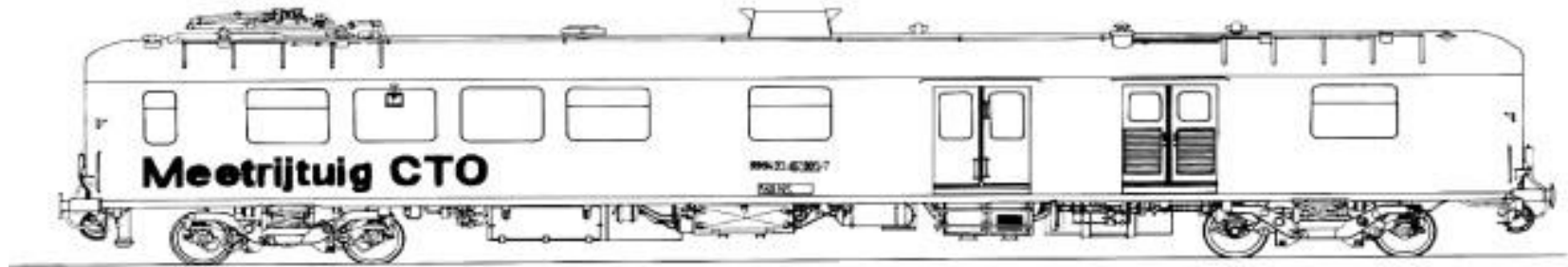
# TU Delft Express

- Innovation = proven technology
- Running lab and class-room
- Testing of knowledge in practice



# Cases: Intelliswitch Rail CTO

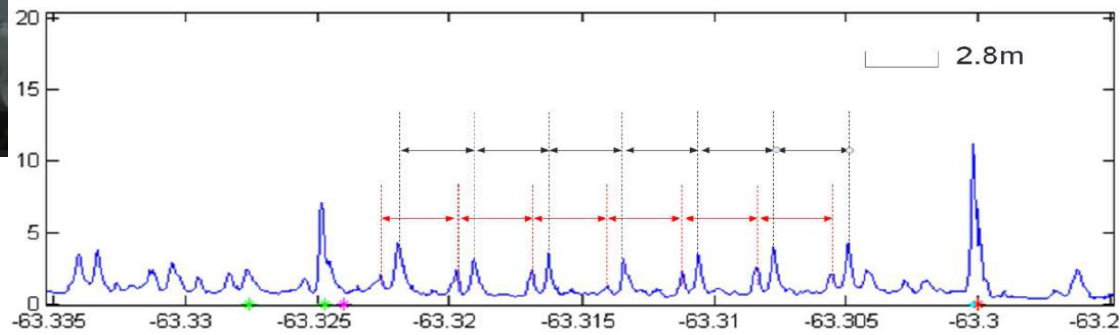
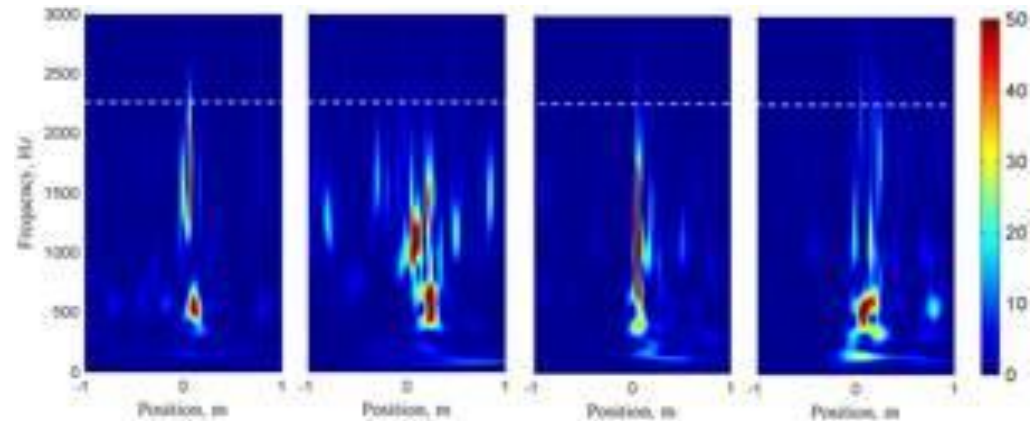
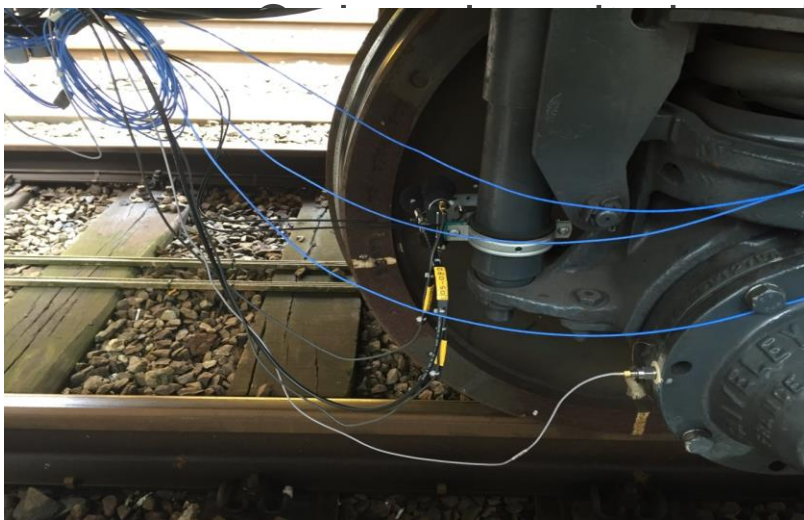
- Railway test platform for rail society
- For **free** (inclusive students....)
- Today: 8 companies work with CTO and TU





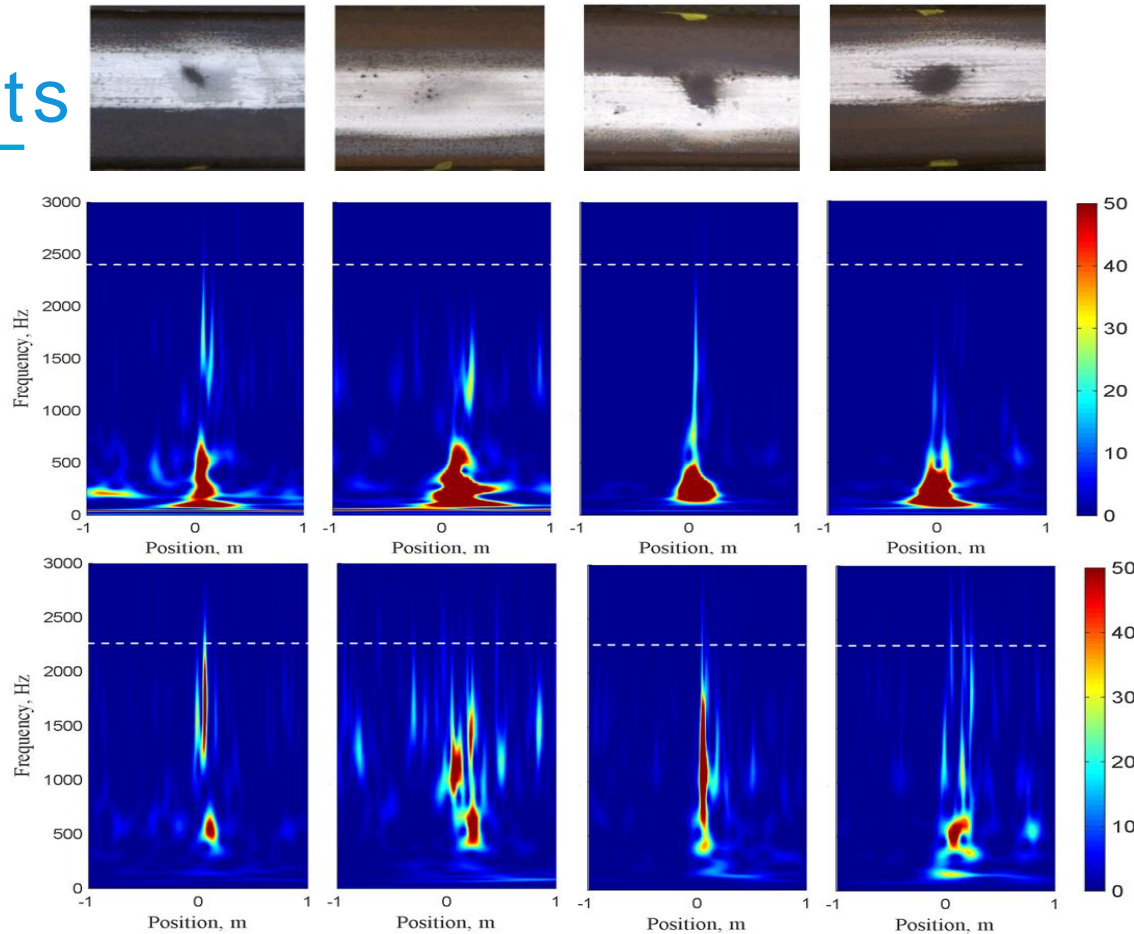
# ABA: axlebox acceleration monitoring

- "baby" Squats detection: 80% hitrate at operational trainspeed



# ABA light squats

- 200 - 400 Hz
- 1000 – 2000 Hz



Z. Li, M. Molodova, A. Núñez, and R. Dollevoet, “Improvements in axle box acceleration measurements for the detection of light squats in railway infrastructure”. IEEE Transactions on Industrial Electronics 62(7): 4385-4397, 2015.  
DOI:10.1109/TIE.2015.2389761

At least 25600 Hz for sampling

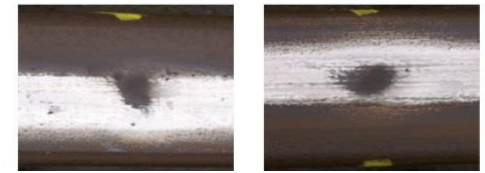
Monitoring the entire Dutch railway (more than 7000 km of rails)

Measurements provides a data volume of several terabytes

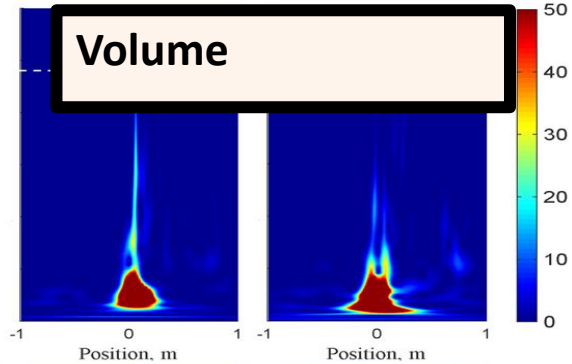
- 1000 – 2000 Hz

At least 16 sensors to assure impact, vertical-longitudinal, left-right rail, trailing leading wheel

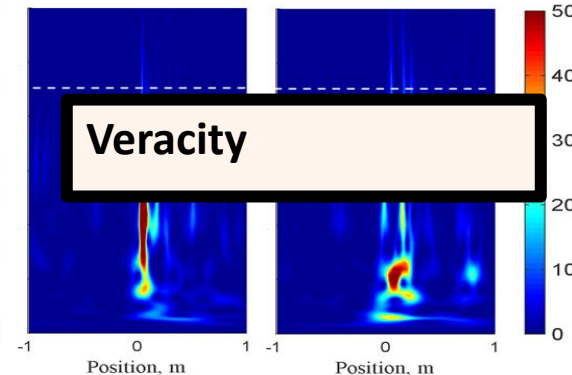
# BIG DATA



**Volume**



**Veracity**





# Data fusion / big data & understanding the physics

Combinations of:

- GPS location
- Substructure
- Soil info
- Geometry
- Phase difference
- Ultrasonics
- Eddy Current
- etc.

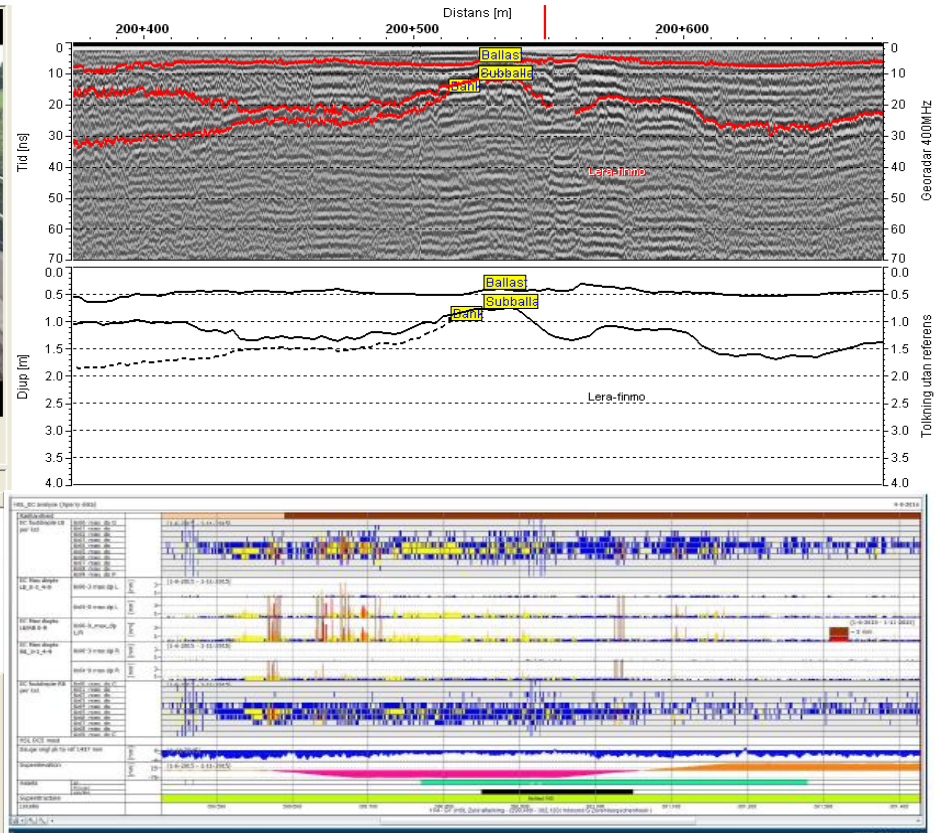
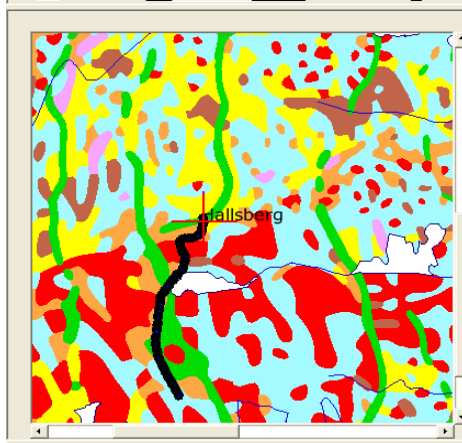
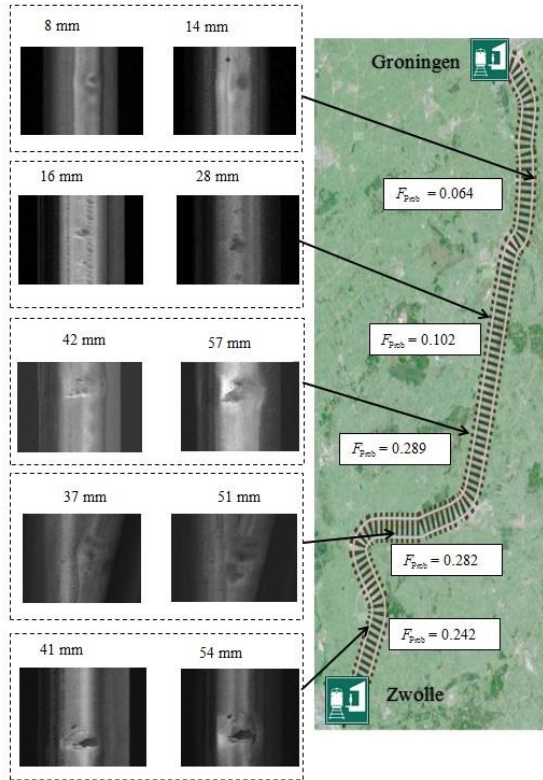
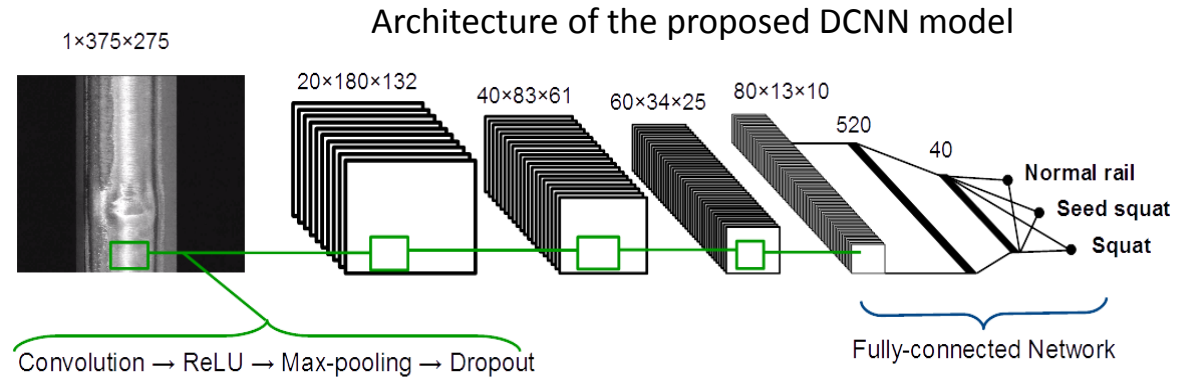


Figure 72: Eddy current measurements in IRISys for the hot spot at the flyover. On the horizontal axis the location position is shown. At the vertical axis some track characteristics are shown. The most important ones are the measurements for the 10 different channels for each leg. The upper shows the measurements for the right leg and the lower one for the left leg. The different colors show the depth: blue: 0,1-1,0mm, yellow 1,0-3,0 mm and red 3,0-5,0mm.

# Big Data based maintenance decision



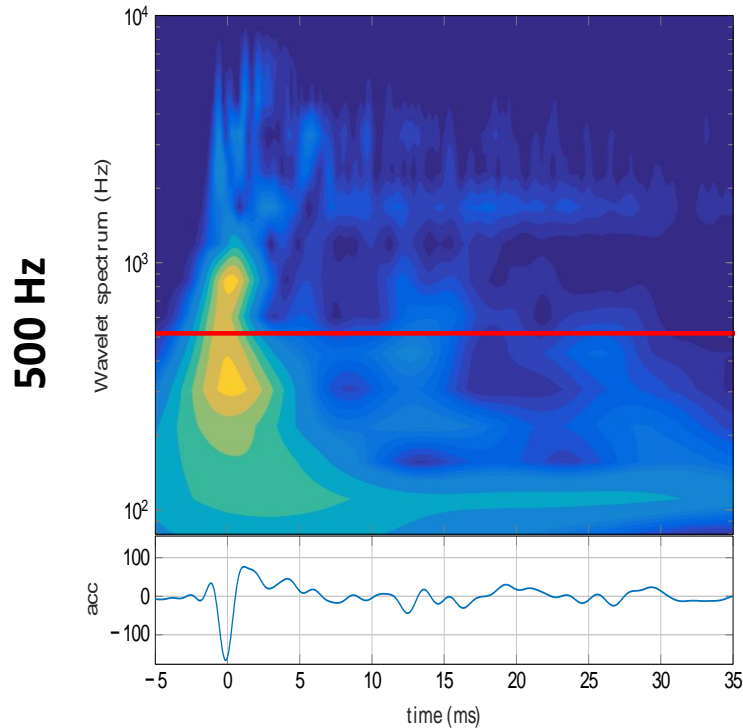
- ❖ A big data analysis approach is used to automatically detect squats from rail images.
- ❖ A Bayesian model is employed to estimate the failure probability.



# Wavelet spectrum switch after crossing/frog

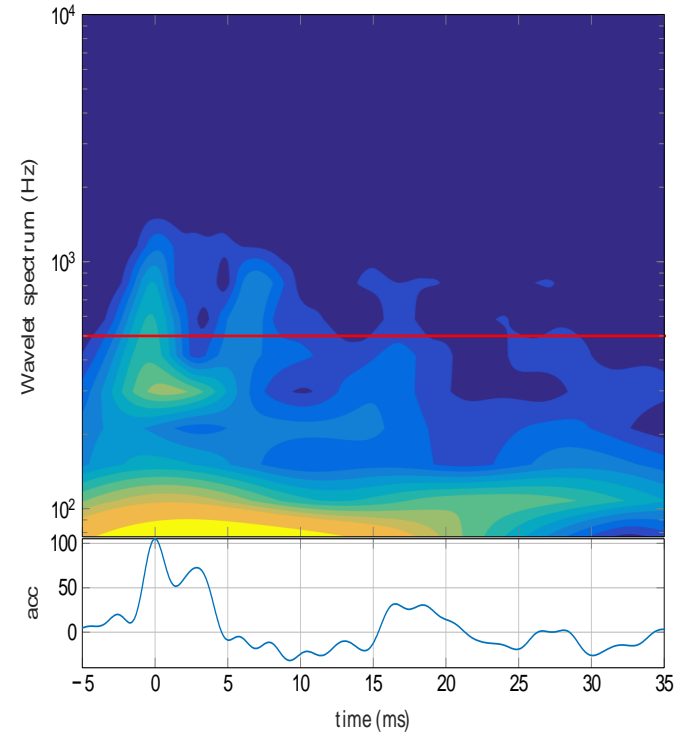
## Wayside

Crossing wheel 3



## Train-borne

Train wheel 3



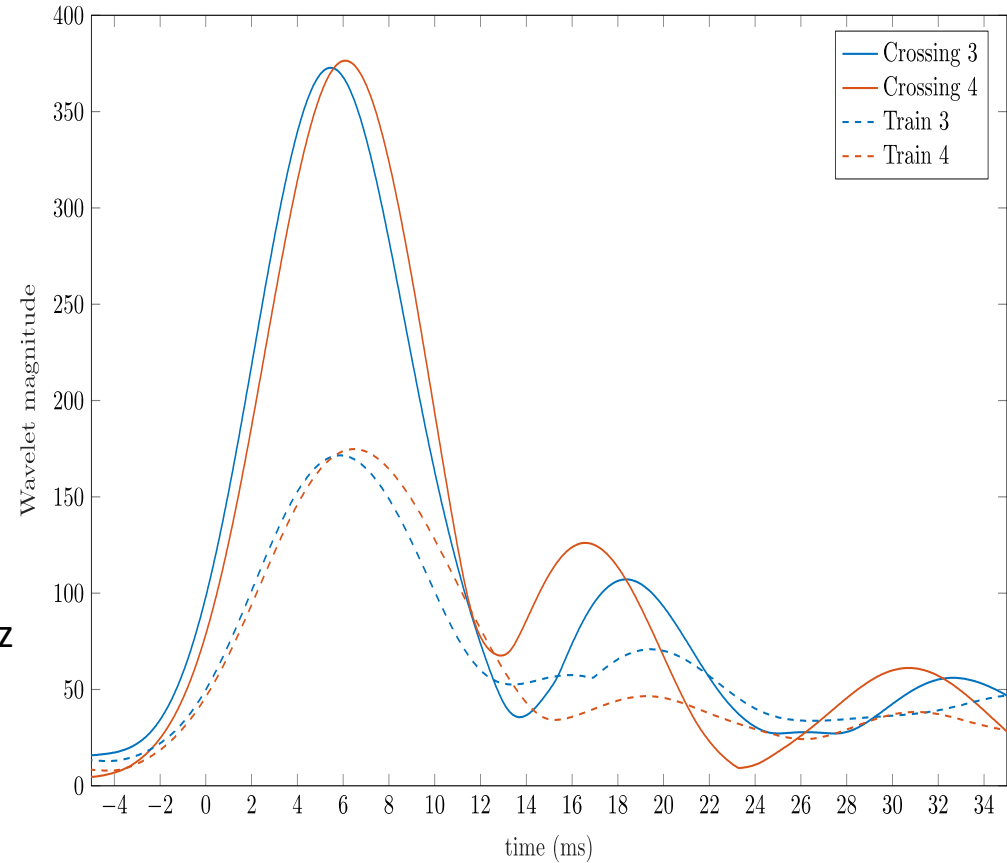


# Wavelet comparison 300 Hz

Blue: leading wheel  
Red: trailing wheel

Blue dots: leading ABA train  
Red dots: trailing ABA train

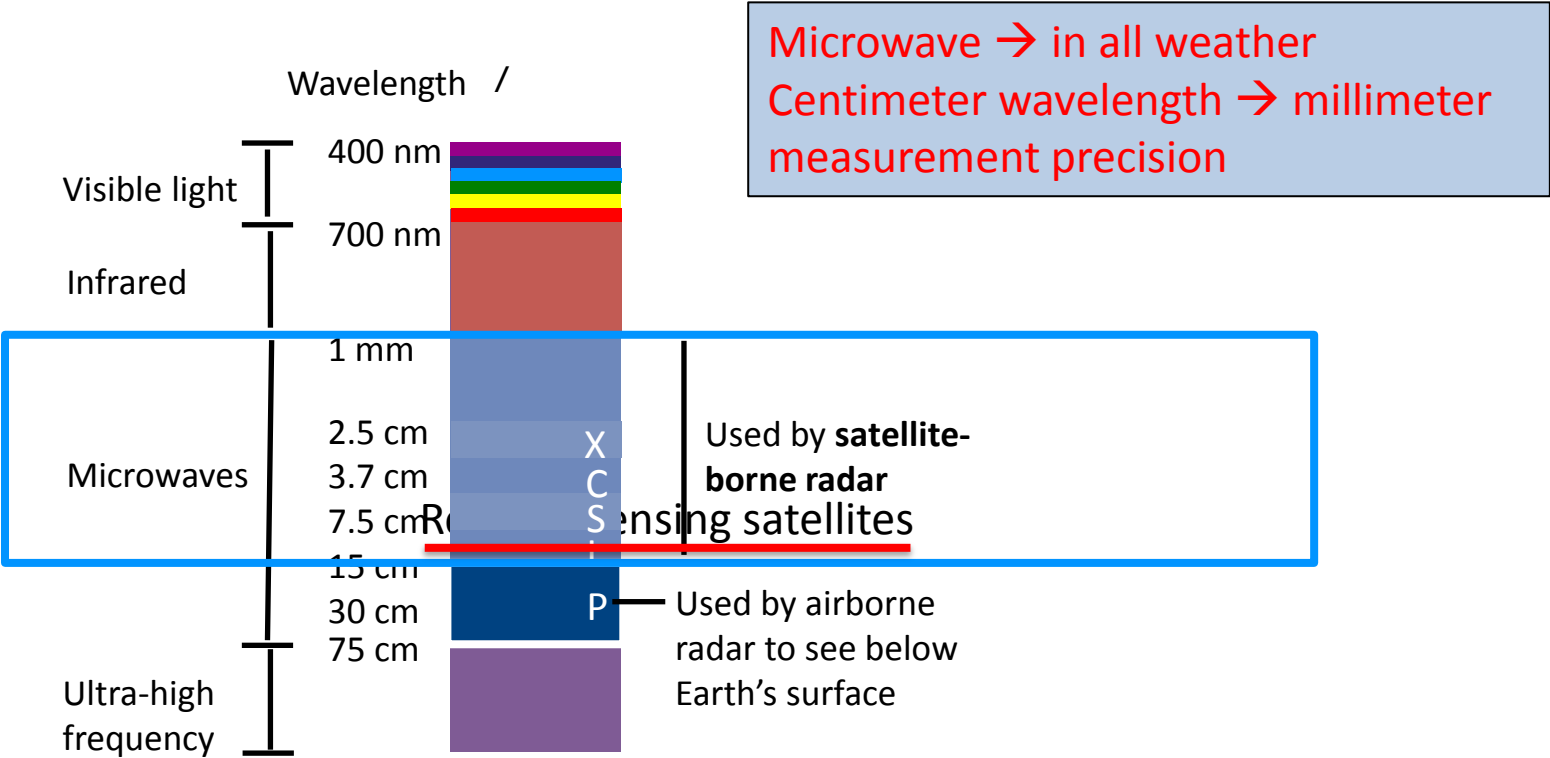
300 Hz

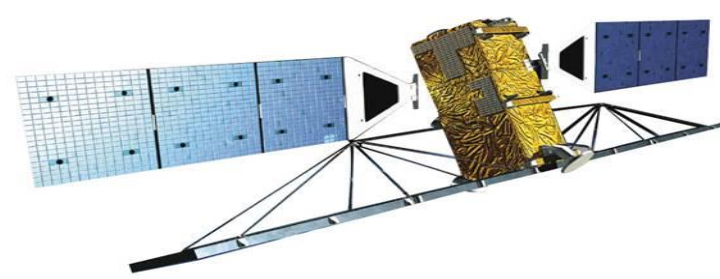


## Conclusion:

Measurements show good repeatability  
Good correlation 100 and 500 Hz with ratio 0.5  
Train-borne monitoring crossings usable till 1 kHz

# Remote Sensing: Microwave



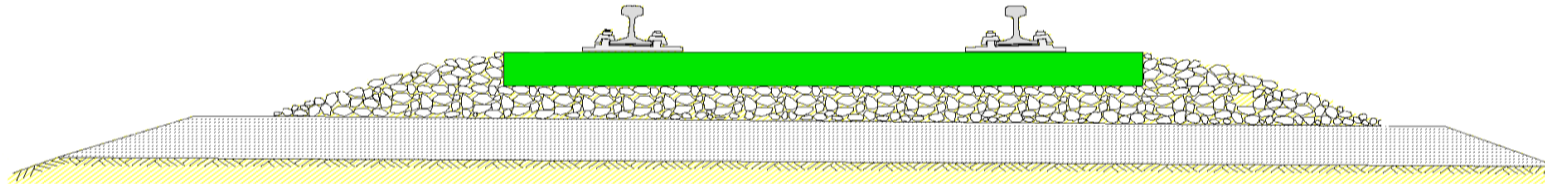
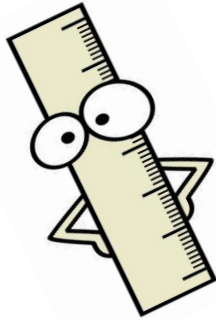


1st pass  
At time  $t_1$

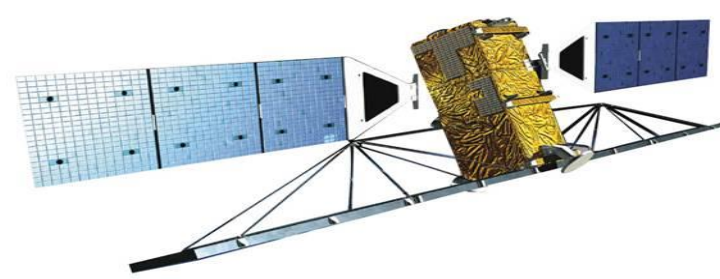
## Satellite measurement:

- **Amplitude** – record the ground target reflection
- **Phase** – record the location/motion of the ground targets  $[-\pi \ +\pi]$

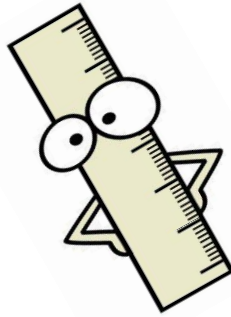
(LOS)  
Line of Sight







2nd pass  
At time  $t_2$



## Satellite measurement:

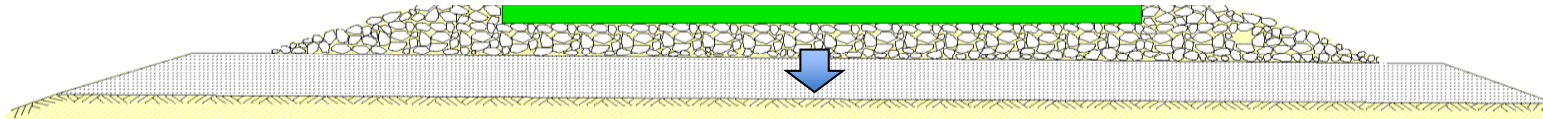
- **Amplitude** – record the ground target reflection
- **Phase** – record the location/motion of the ground targets  $[-\pi \quad +\pi]$

$f^{1,2}$

→ calculate the **phase difference** between  $t_1$  and  $t_2$  -- the **settlement value** is obtained



# Satellite Radar Interferometry (**InSAR**) techniques



Q: Can these satellites observe every ground object in railway infrastructure environment?

Train  
Rails  
Embankment  
Poles  
Catenary  
Sleepers  
Squat  
Grass  
Tree ...



Q: Can these satellites observe every ground object in railway infrastructure environment?

Train

Rails

Embankment



Poles

Catenary

Sleepers

Squat

Grass

Tree ...


















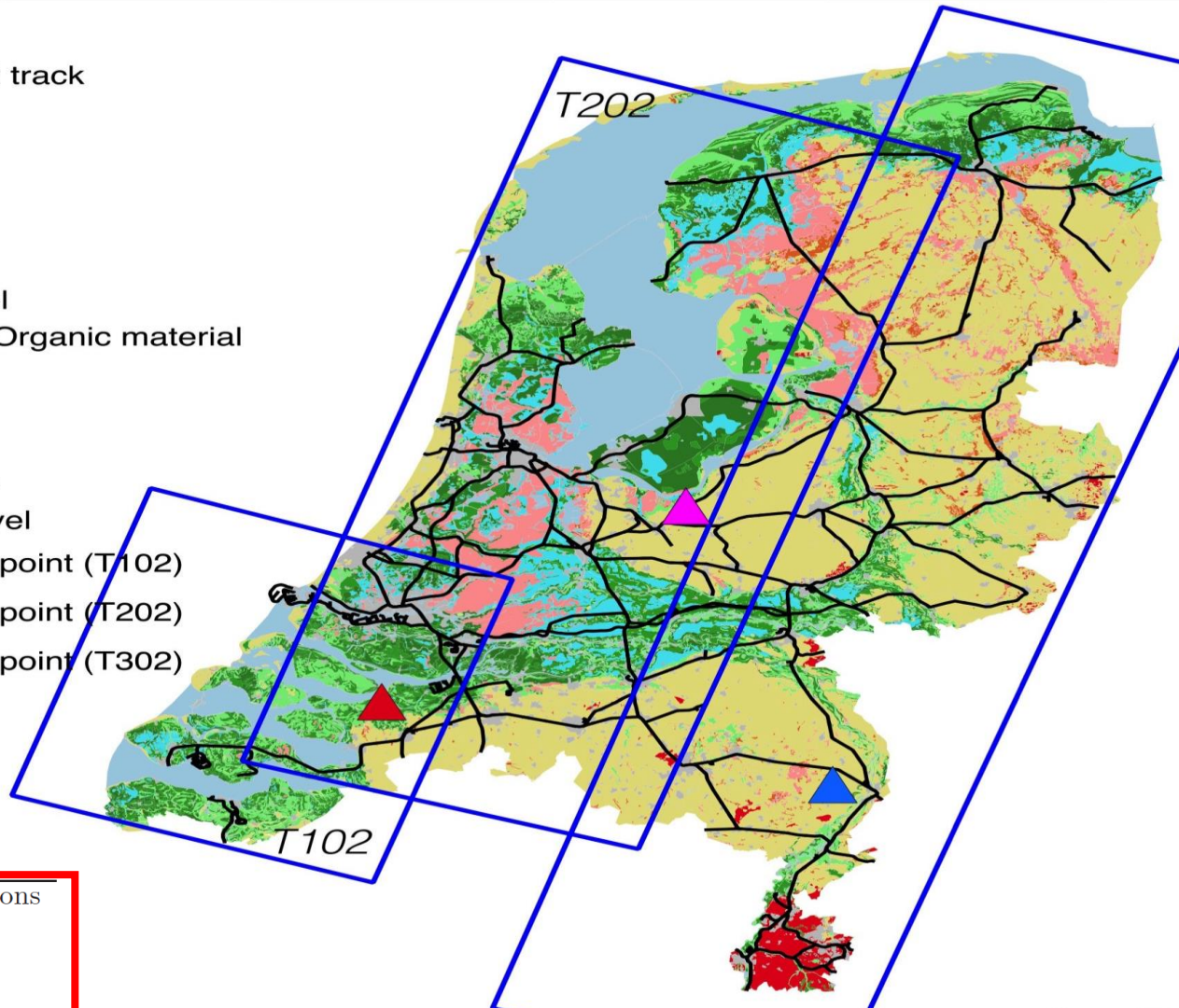


## Good to know....

- Radar satellite delivers data in **all weather**, since **1992**, some medium-resolution data are **free**
- Radar satellite data are
  - in **millimeter-estimation** precision
  - **routinely** updated
  - **wide**-scale, e.g. ~100 km swath
  - used for railway infrastructure **permanent settlement/deformation** monitoring, not for railway dynamic deformation monitoring

## Legend

-  Radarsat-2 track
-  Railway
- Soil (2006)
  -  Buildings
  -  Silt
  -  Light clay
  -  Light gravel
  -  Sand with Organic material
  -  Peat
  -  Water
  -  Sand
  -  Heavy clay
  -  Heavy gravel
-  Reference point (T102)
-  Reference point (T202)
-  Reference point (T302)



Track Nr.	Start/End Date	Acquisitions
T102	2010-06-13 – 2015-06-11	72
T202	2010-06-20 – 2015-08-05	69
T302	2010-06-03 – 2015-06-25	72

# Nation-wide rail-deformation

## Legend

### Linear velocity

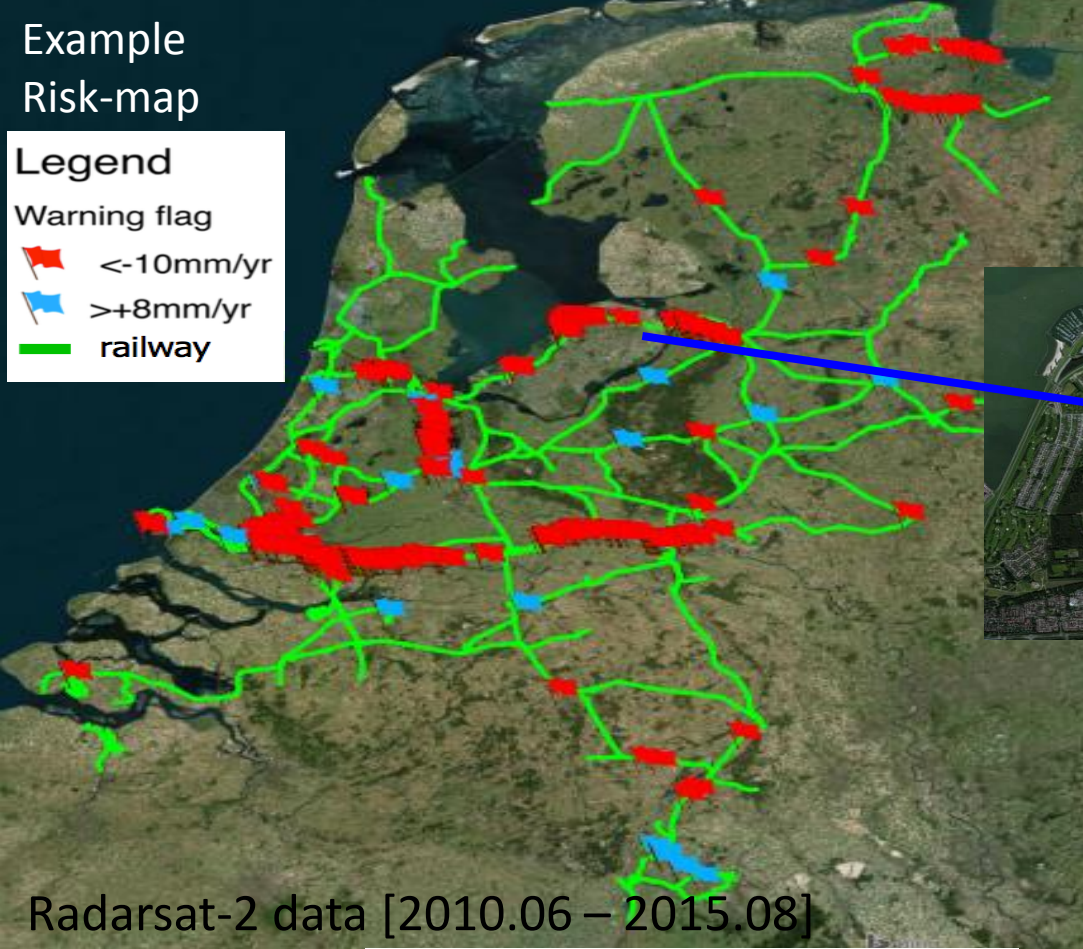
- $< -10\text{mm/yr}$
- $-10 - -6$
- $-6 - -2$
- $-2 - +2$
- $+2 - +6$
- $+6 - +10$
- $> +10\text{mm/yr}$

- In gebruik voor reizigers- (en goederen)treinen
- In use for passenger (and cargo) trains
- Alleen goederenvervoer / Cargo trains only
- Betuweroute
- Museumspoorweg
- Heritage railway

## Readability for non-InSAR people

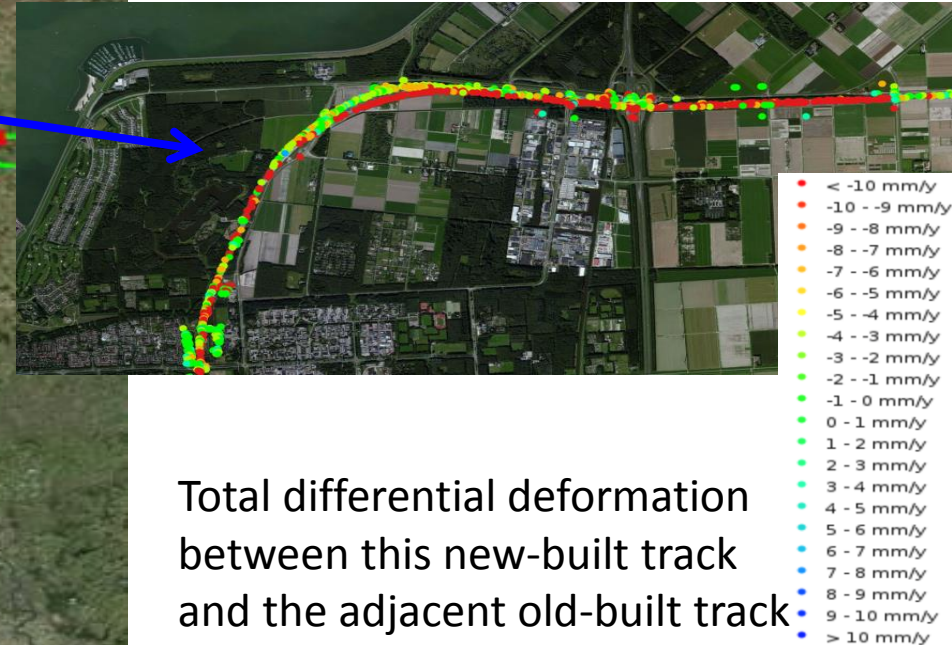
Radarsat-2 data [2010.06 – 2015.08]





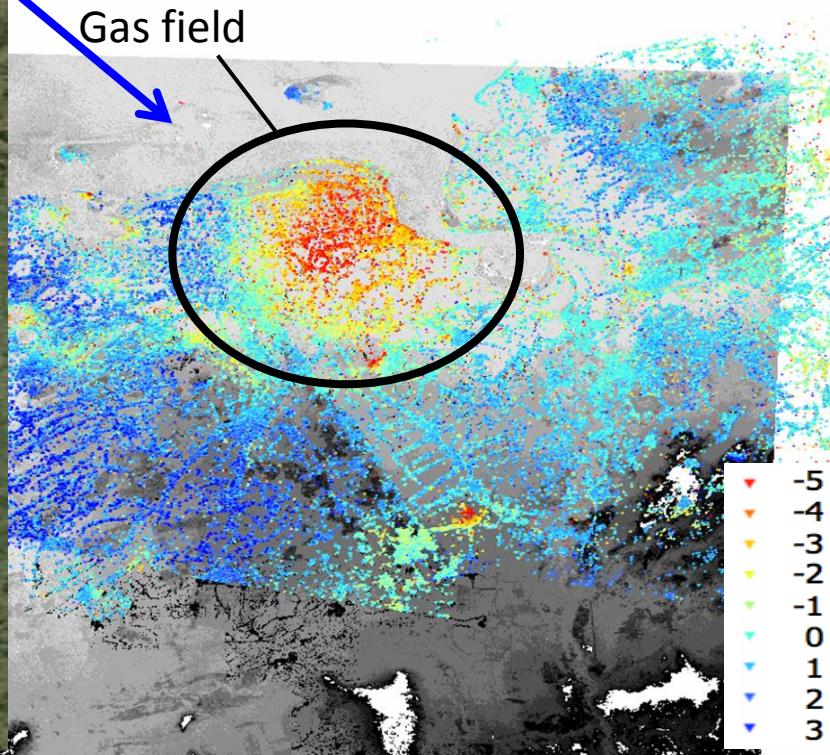
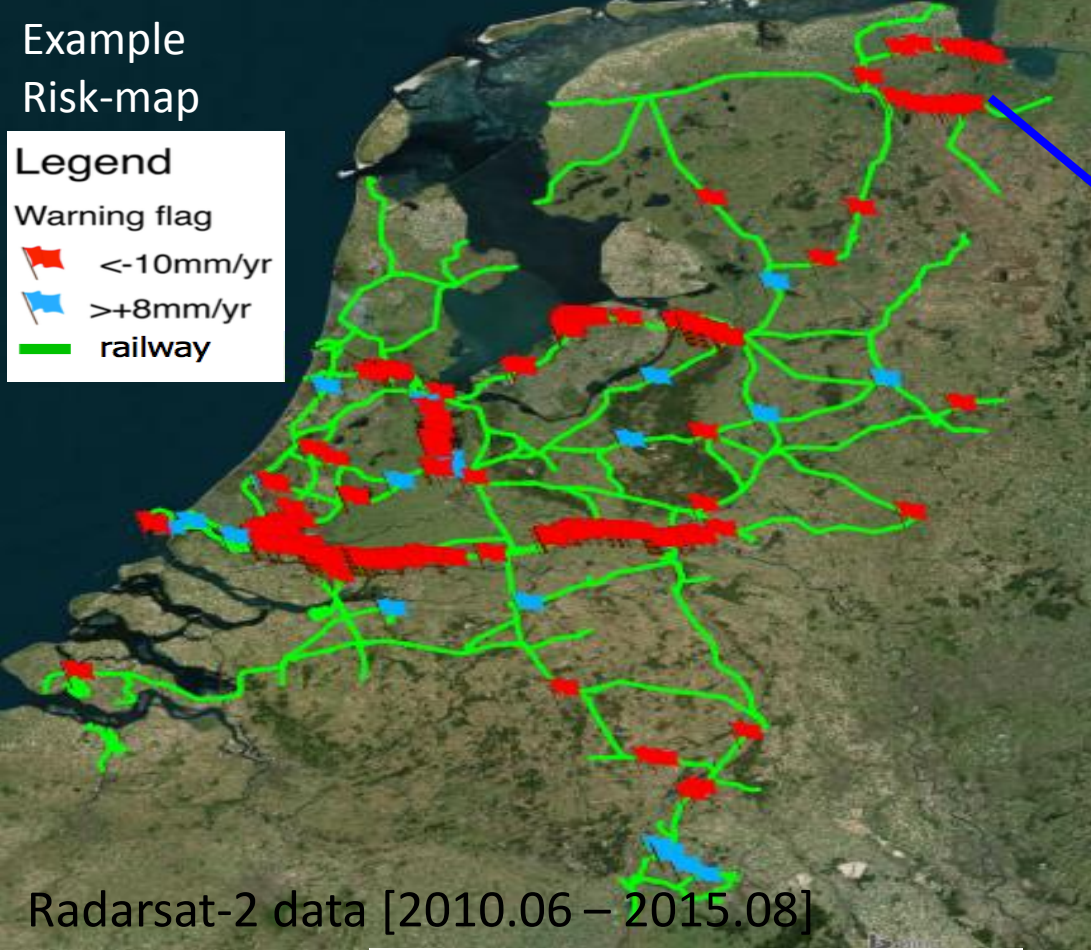
(‘risk’ to be defined by end user)

New-built tracks, Lelystad area  
(Hanzelijn)



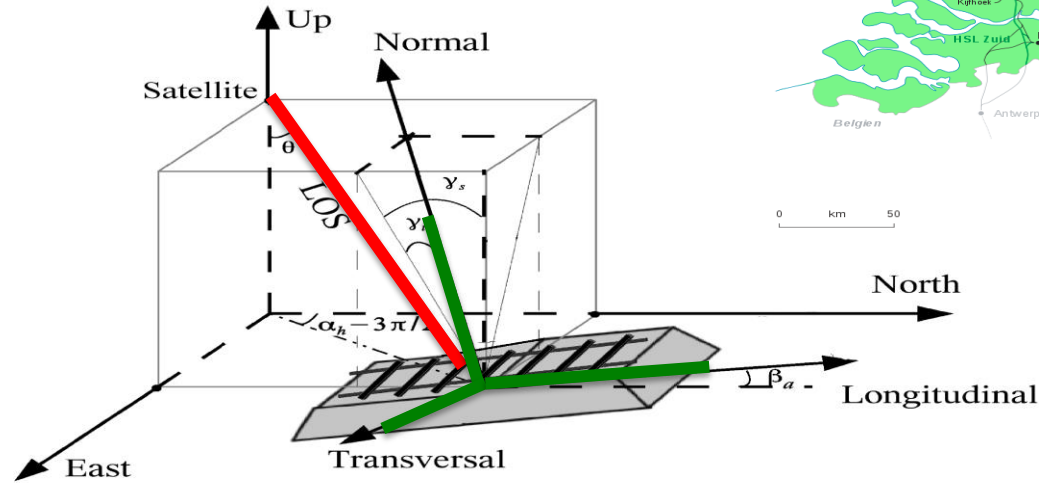
Total differential deformation  
between this new-built track  
and the adjacent old-built track  
is up to **~50 mm** in [2010/2015]





(‘risk’ to be defined by end user)

# LOS-vector decomposition



Rotation matrices:

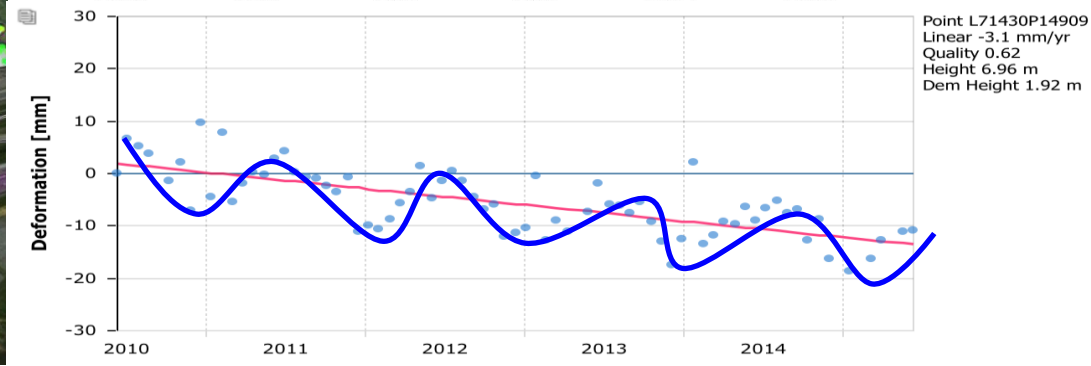
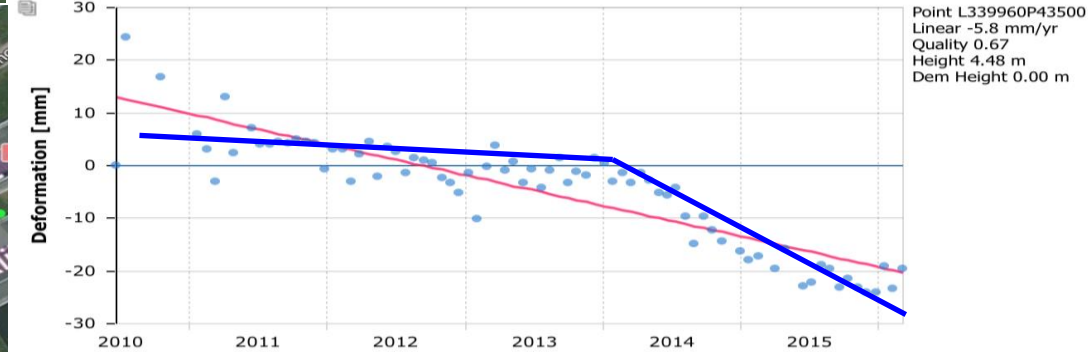
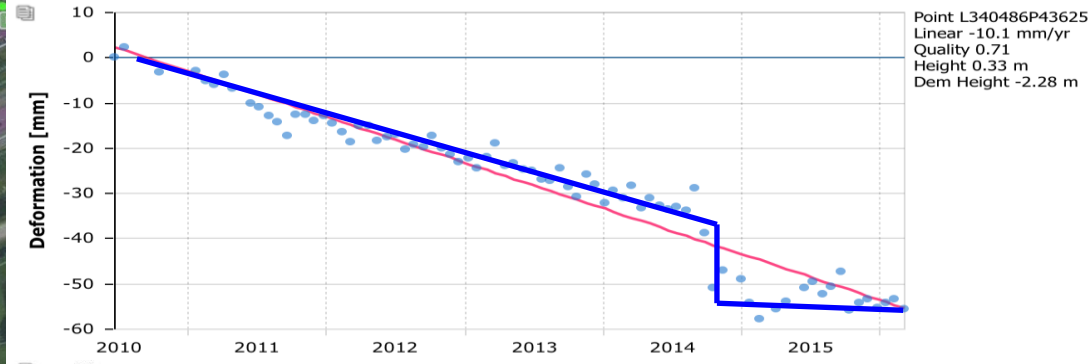
$$R_1 = \begin{bmatrix} \cos \beta & \sin \beta & 0 \\ -\sin \beta & \cos \beta & 0 \\ 0 & 0 & 1 \end{bmatrix}, R_2 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \gamma_s & -\sin \gamma_s \\ 0 & \sin \gamma_s & \cos \gamma_s \end{bmatrix}, R_3 = \begin{bmatrix} \cos \gamma_t & 0 & \sin \gamma_t \\ 0 & 1 & 0 \\ -\sin \gamma_t & 0 & \cos \gamma_t \end{bmatrix}$$

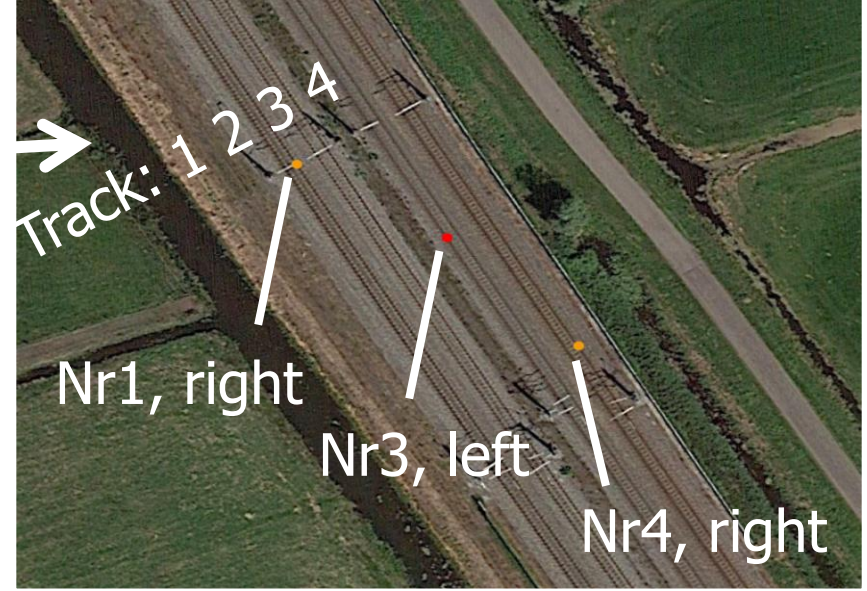
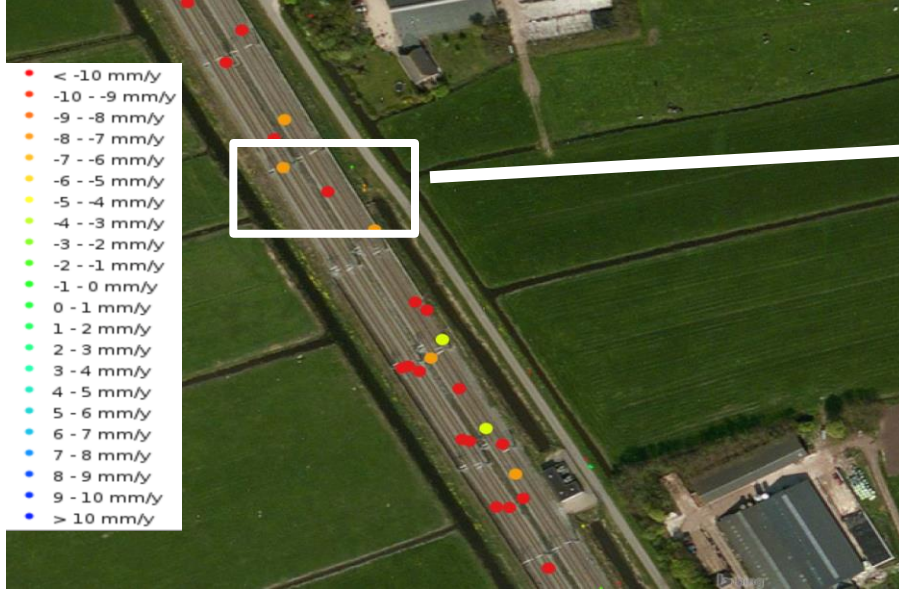
$$d_{\text{geo}} = R_1 R_2 R_3 d_{\text{track}}$$

$$d_{\text{track}} = [d_T, d_L, d_N]^T$$

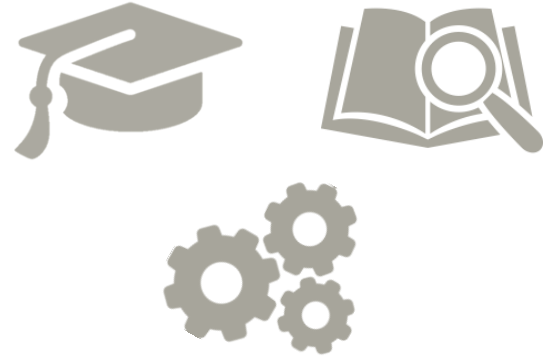


# Examples





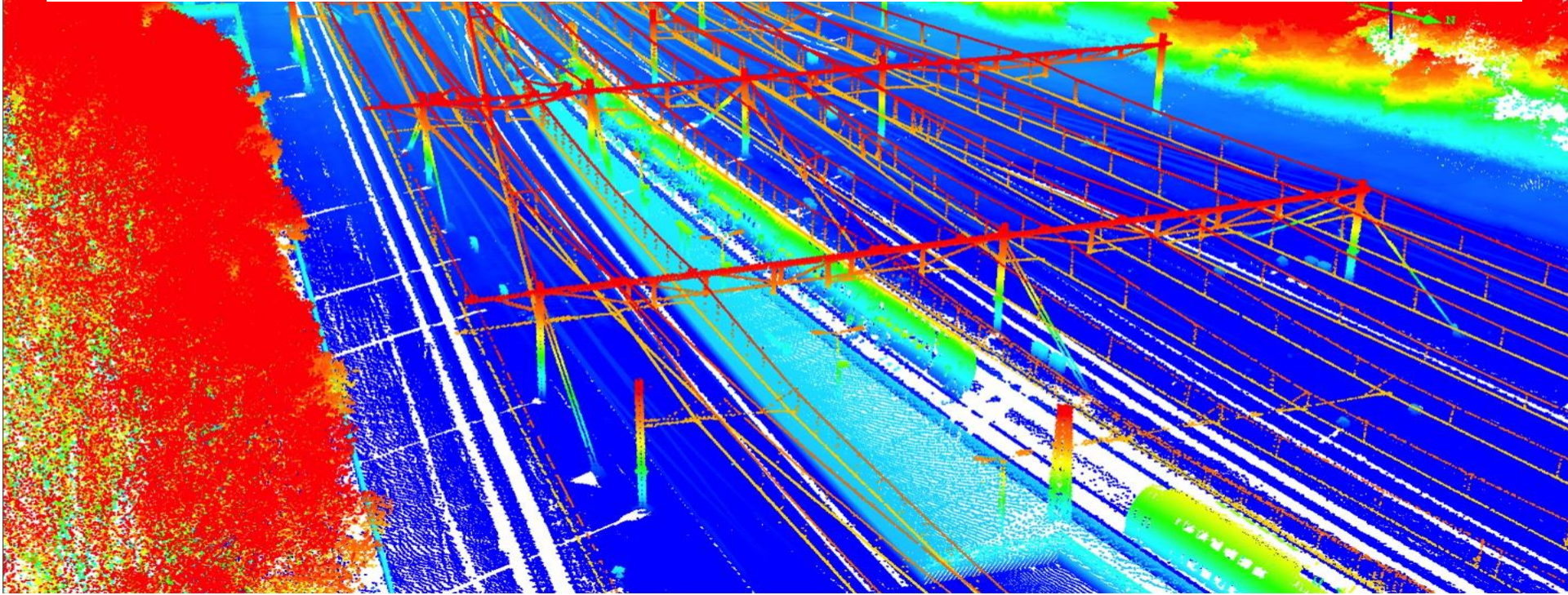
Q: How do we turn this into 'information'?





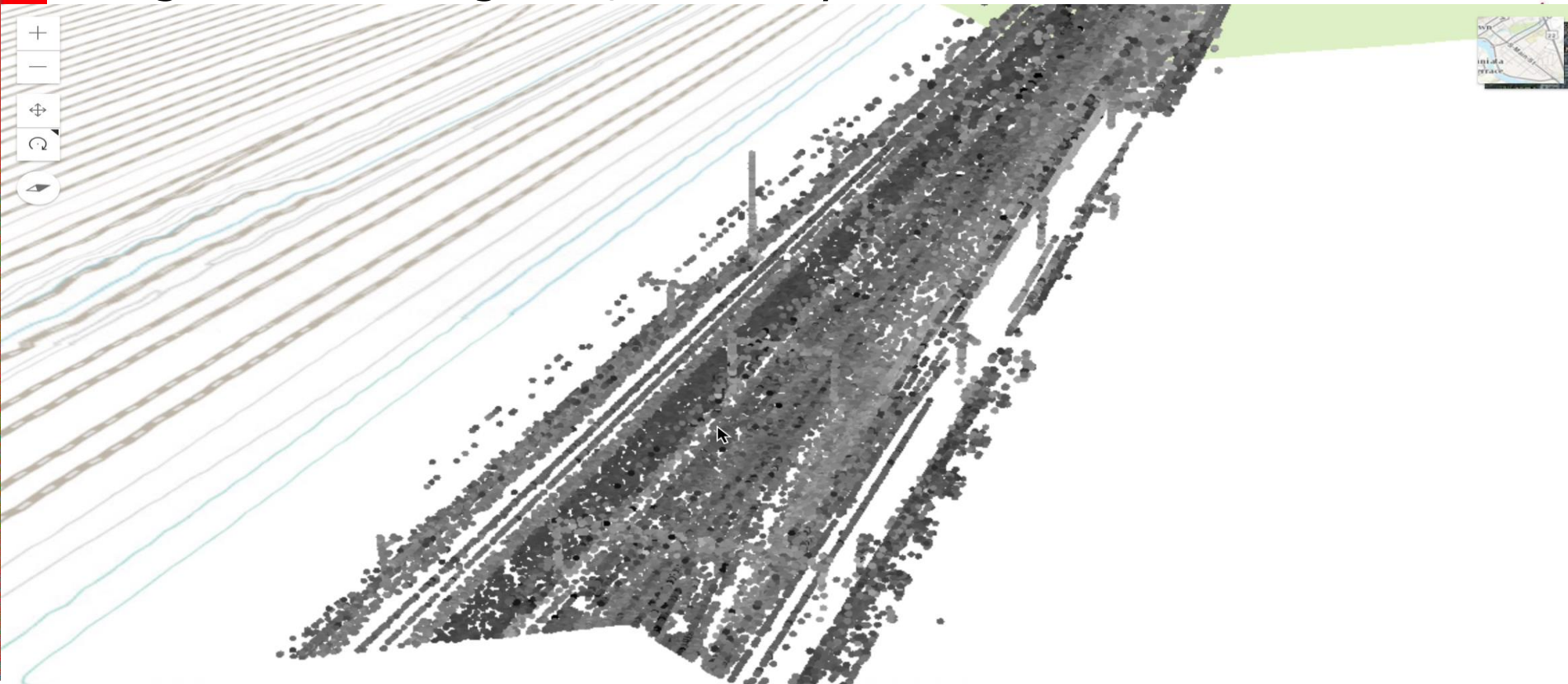
# Linking the satellite reflections to assets.

Using laser scanning data, link every satellite measurement to a specific asset.



# Linking the satellite reflections to assets

Using laser scanning data, link every satellite measurement to a

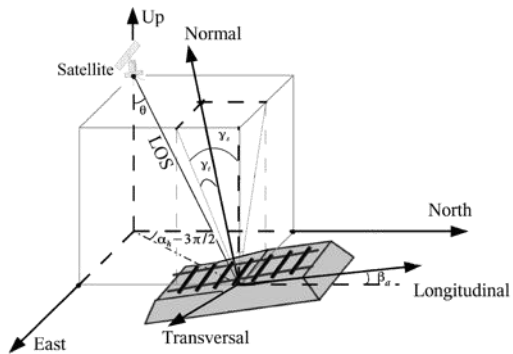




# Miss InSAR space

Dr. Ling Chang, TU Delft



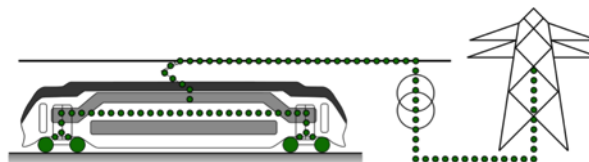


2 – 5 years

5 – 10 years

20 years

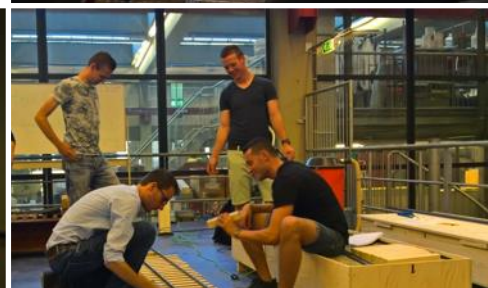
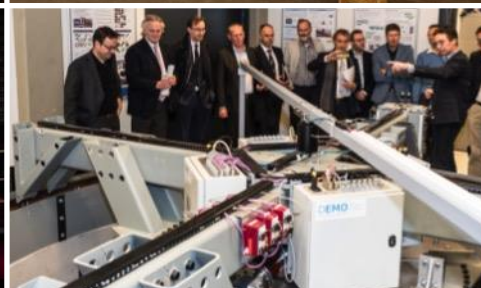
50 years







[www.railahead.nl](http://www.railahead.nl)



Thanks to my  
COLLEAGUES !

