# RIEGL
# Mobile Laser Scanning
# Railway Application

Dr. Harald Teufelsbauer
Business Division Manager, MLS
May 2019

RIEGL®

Innovation in 3D

## Agenda

1. Introduction: short company presentation of RIEGL
2. Mobile Laser Scanning systems: system configuration and key features
3. Processing Software > automated data alignment
4. LiDAR systems in Rail: types of applications and methods

   > large scale (MLS)  > mid scale (ULS)  > small scale (TLS)
5. Case Study 1: Data Fusion - combining the advantages of different scanning methods
6. Case Study 2: Subway Scanning – reliable surveying in GNSS denied areas
7. Case Study 3: Tunnel Modeling – cost reduction in construction projects based on high definition 3D models

*RIEGL* Laser Scanning | RAIL Application

RIEGL

# RIEGL Mobile Mapping Systems

## VMX-250

first RIEGL MLS system

2010

## VMX-450 RAIL

specific adaption for rail application

2013

## VMX-2HA

utmost flexibility for road and rail application

2017

## VMX-RAIL

first triple scanner system designed for rail application

2018

Mobile Laser Scanning | time line

# VMX – RAIL

***Triple Scanner Mobile Mapping System***

***Specifically Designed for Rail Application***


VMX-RAIL | designed for harsh conditions

RIEGL®

## VMX-RAIL Key Features

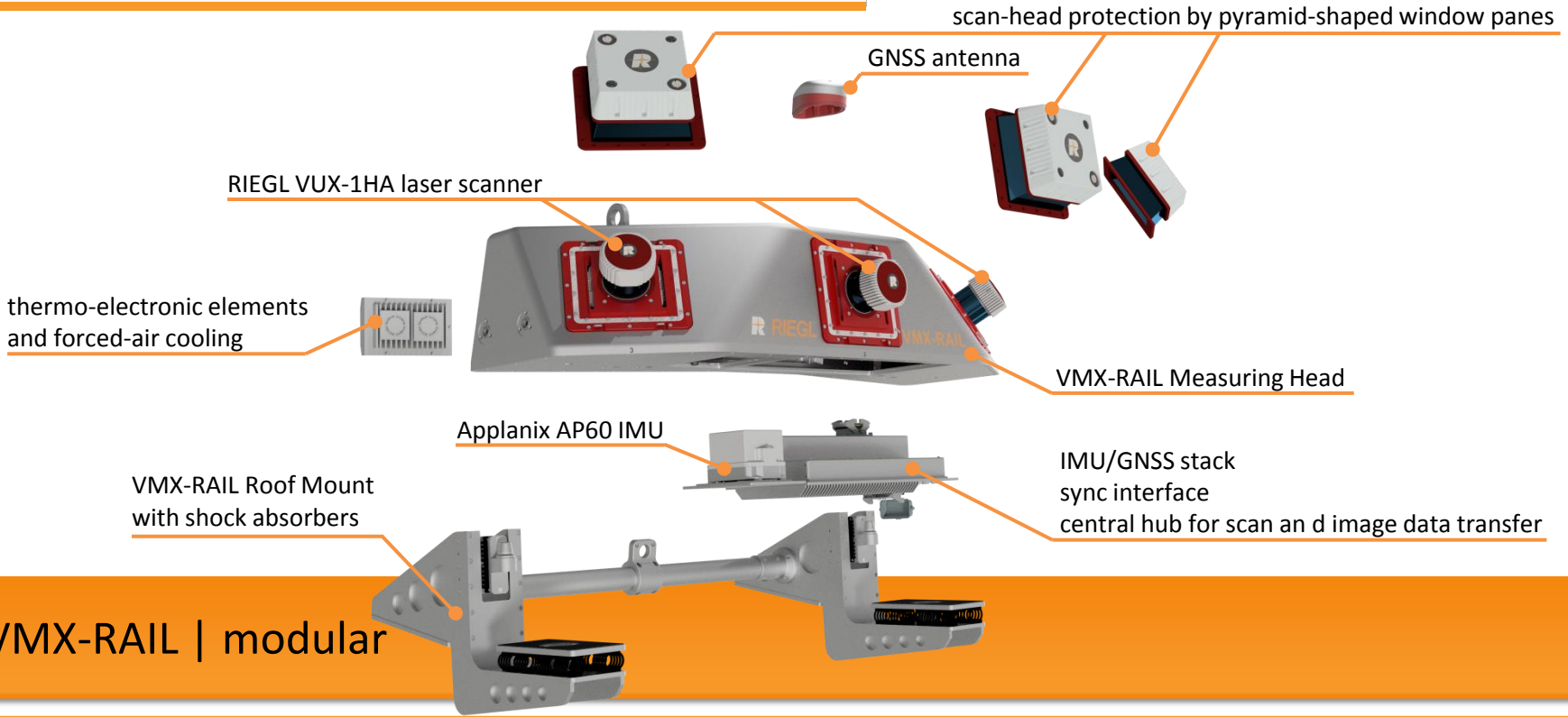
- rugged measuring head for reliable long-term operation in harsh environments
- equipped with three VUX-1HA High Accuracy Laser Scanners
- **3 MHz** pulse repetition rate and **750 lines per second** resulting in up to **7000 pts/m²** in 3m range at 80 km/h platform speed


VMX-RAIL | key features

# VMX-RAIL System Components


## VMX-RAIL | modular

# VMX-RAIL System Components




## VMX-RAIL | modular

# VMX-RAIL Camera System

## 10 GigE High Capacity Data Transfer

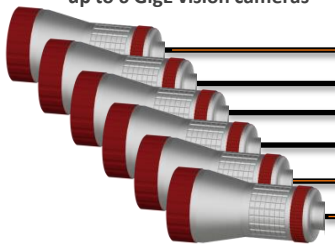
- VMX-RAIL supports up to 6 cameras (5Mp, 9Mp, 12Mp)
- leading edge CMOS technology enables high resolution and high frame rates
    - equipped with a wide angle, low distortion lens (e.g. 12Mpx with 83° x 66° FOV)
    - ball-joint camera heads for v × h rotation
    - high-speed imaging up to 20 fps
- Image data traffic up to 6 Gbit/s
- Ladybug 5+ for spherical imaging


VMX-RAIL | camera system

# VMX-RAIL Interfaces

spherical imaging Ladybug 5+ USB3

up to 6 GigE vision cameras



Interface Unit

10 GigE

pwr

trigger unit

Sync: COM2, COM3, PPS, NMEA, DMI

Data: Scanner, IMU

**Main Cable**

- Power supply
- Cam data 10 GigE fiber optic
- COM3, DMI
- Scan data 1GigE Cat 5

**Control Rack**

- Acquisition PC
- Linux OS
- 4.8 TB SSD storage
- UPS failsafe operation

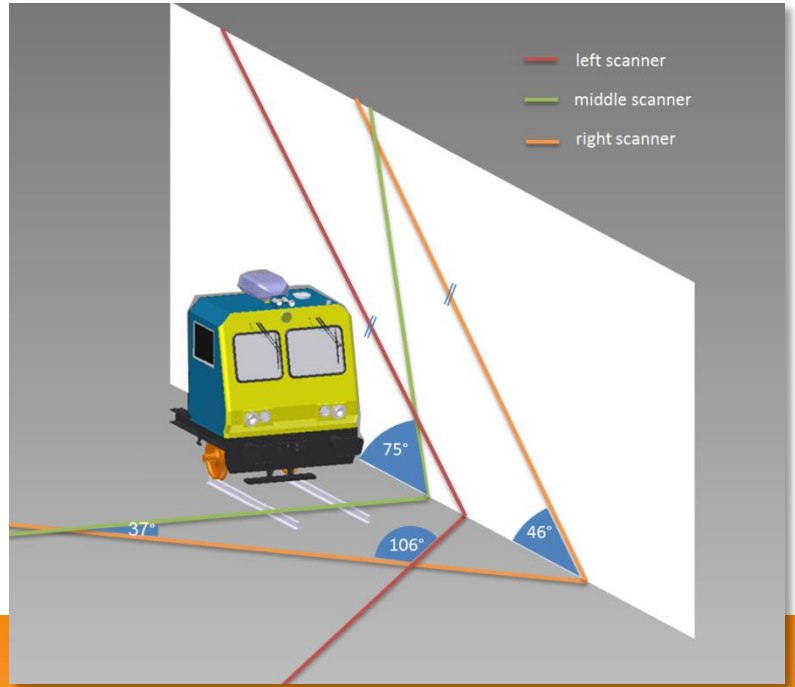
min. space requirement 500 cm


## VMX-RAIL | interfaces

# VMX-RAIL Key Features

- unique crossed point cloud pattern along 360 deg of the clearance profile
- optimized scanner orientation to increase the field of view and to minimize scan shadows

➡ improved feature extraction and small object detection




VMX-RAIL | point cloud pattern

# VMX Scan Pattern

**Illustration of typical VMX scan pattern**

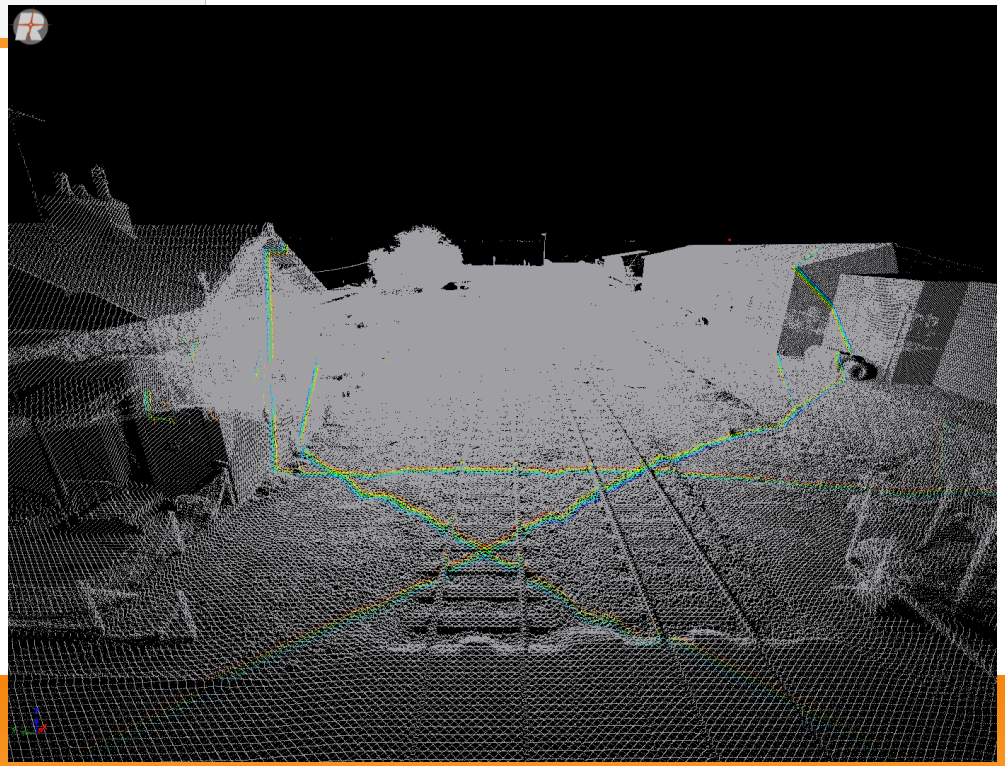
- Simultaneous forward/backward looking
- Crossed scan lines in a single pass
- Crossed scanlines also on objects parallel to the trajectory
- Reduction of scan shadows caused by obstacles and traffic
- Get three sides of a structure (columns, house facades, trafic signs, …) in one pass

VMX-RAIL | point cloud pattern

# VMX Scan Pattern

**Illustration of typical VMX scan pattern**

- Simultaneous forward/backward looking
- Crossed scan lines in a single pass
- Crossed scanlines also on objects parallel to the trajectory
- Reduction of scan shadows caused by obstacles and traffic
- Get three sides of a structure (columns, house facades, trafic signs, …) in one pass



VMX-RAIL | point cloud pattern

# VMX Scan Pattern

**Case Study 80km/h platform speed**

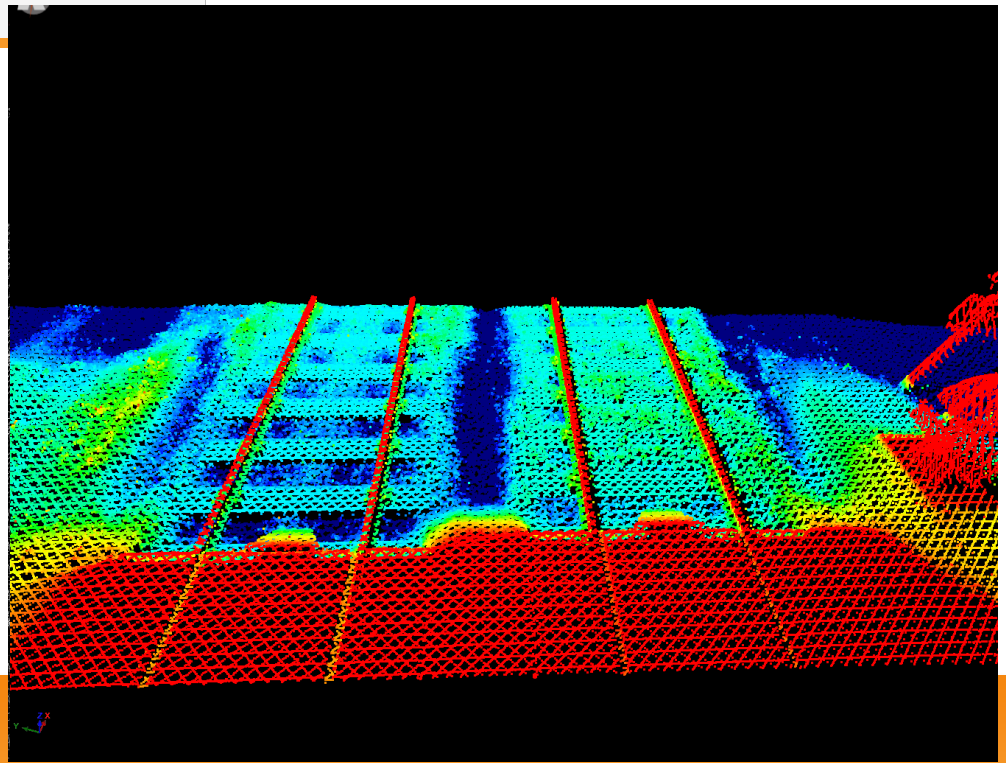
pulse repetition rate = **3 Mhz**
scan line density = **750 lines per second**
platform speed = **80 km/h**

**Results @ 3 m target distance @ 80 km/h**

scan line distance = **9 cm** per scanner
point spacing = **< 5 mm** per scanner
TOTAL points per $m^2$ = **7000**

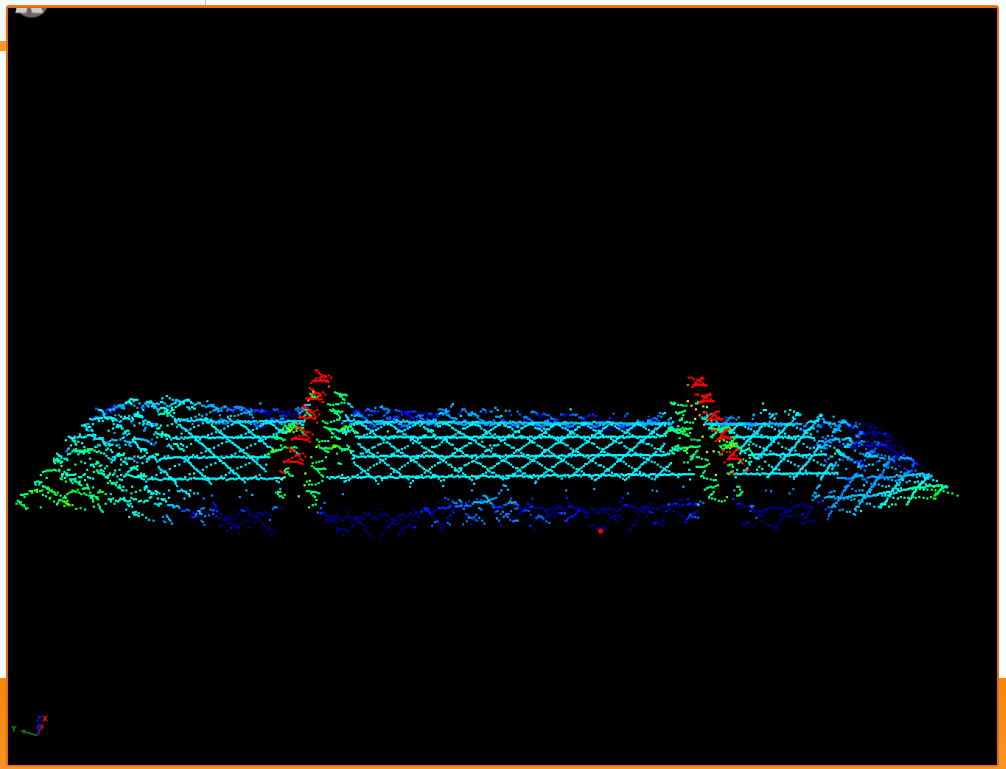
VMX-RAIL | point cloud pattern

# VMX Scan Pattern



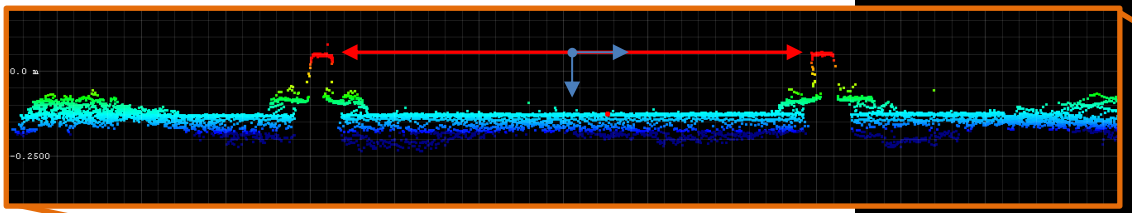
VMX-RAIL | point cloud pattern

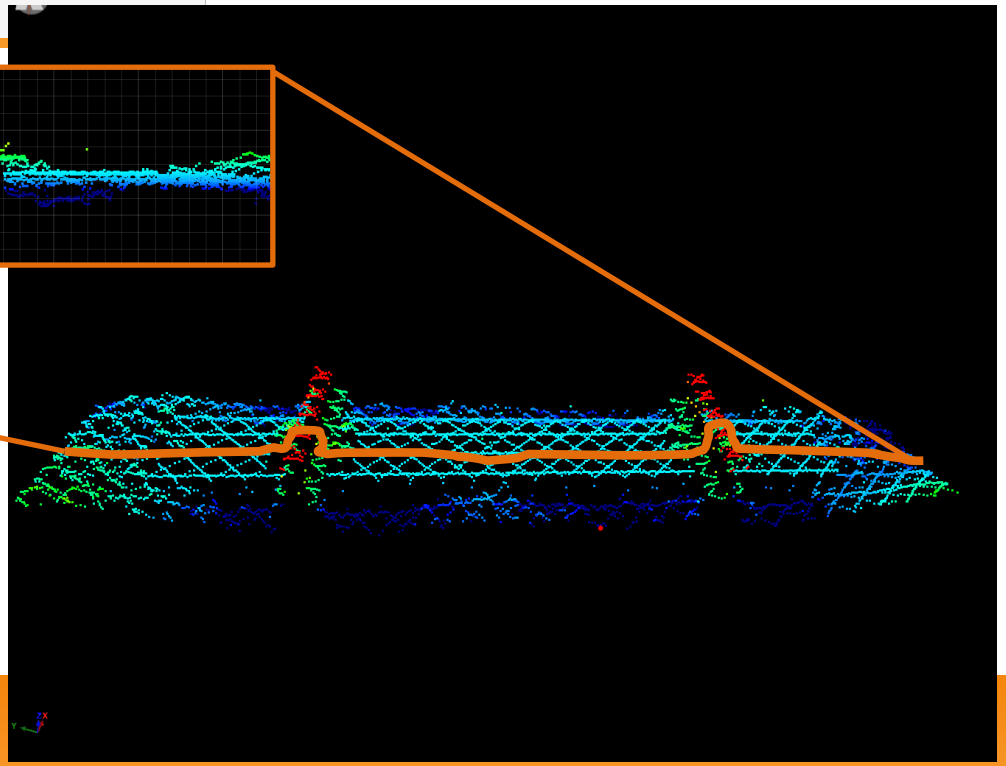
# VMX Scan Pattern



VMX-RAIL | point cloud pattern

# VMX Scan Pattern

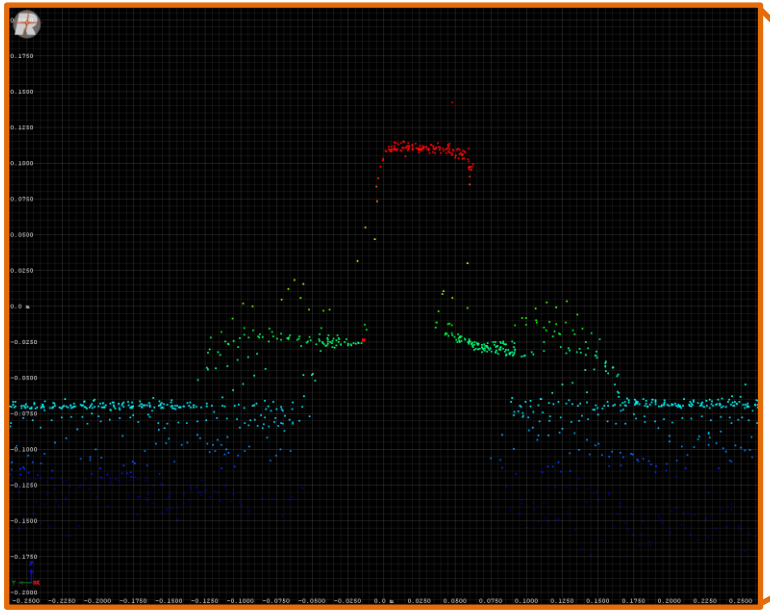


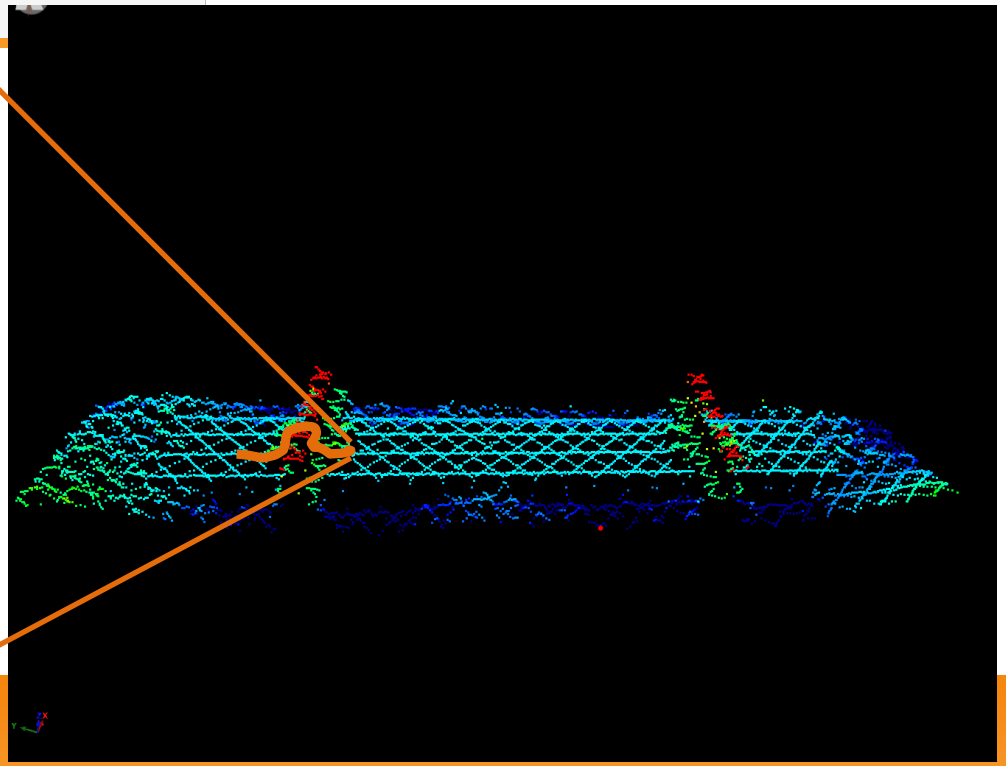


- extraction of rail position and width
- measurement of superelevation
- calculation of 6 DOF rail axes

VMX-RAIL | point cloud pattern

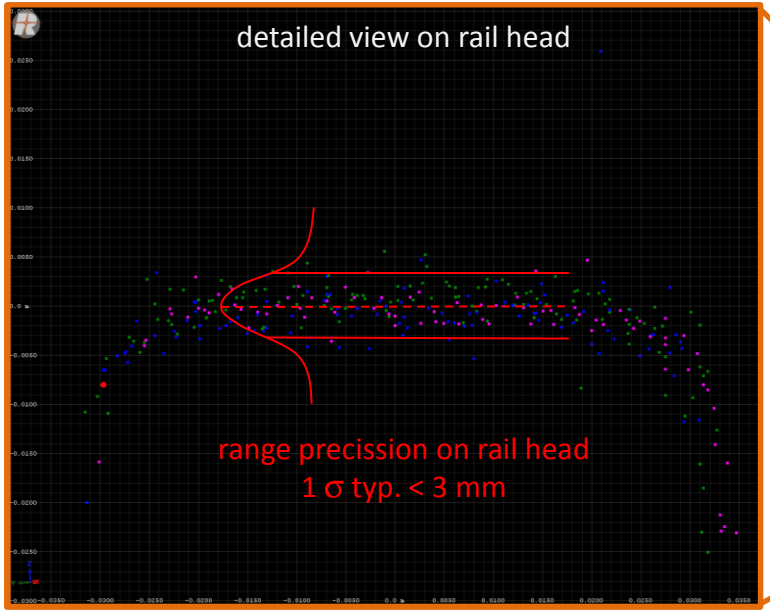
# VMX Scan Pattern

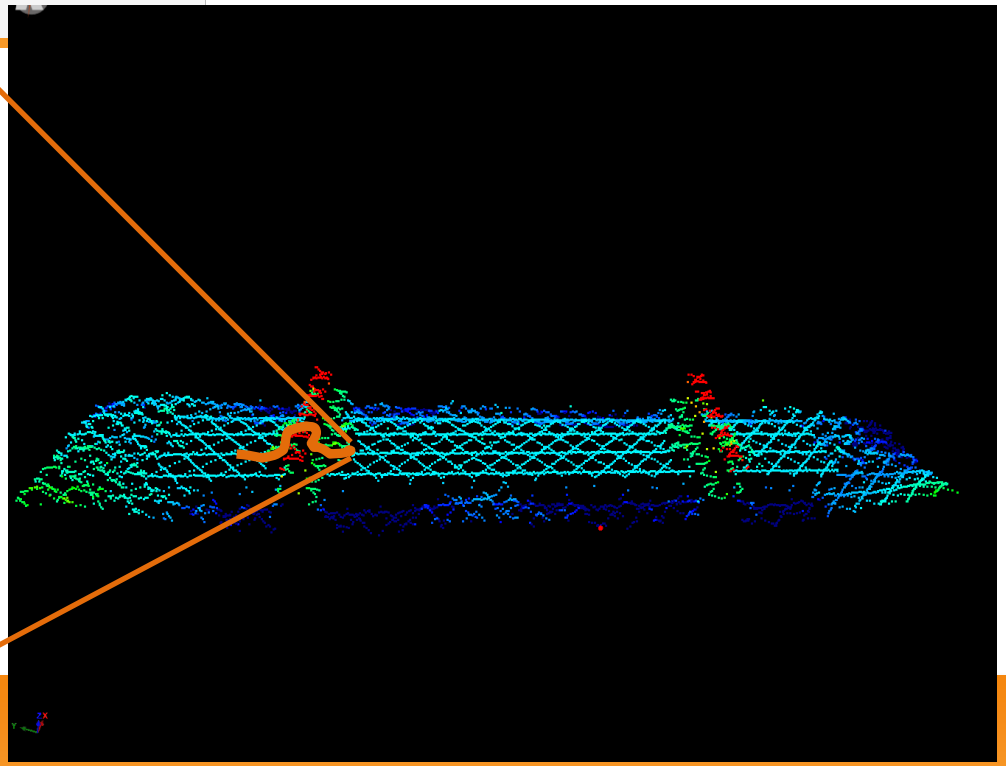




VMX-RAIL | point cloud pattern

# Accuracy Evaluation



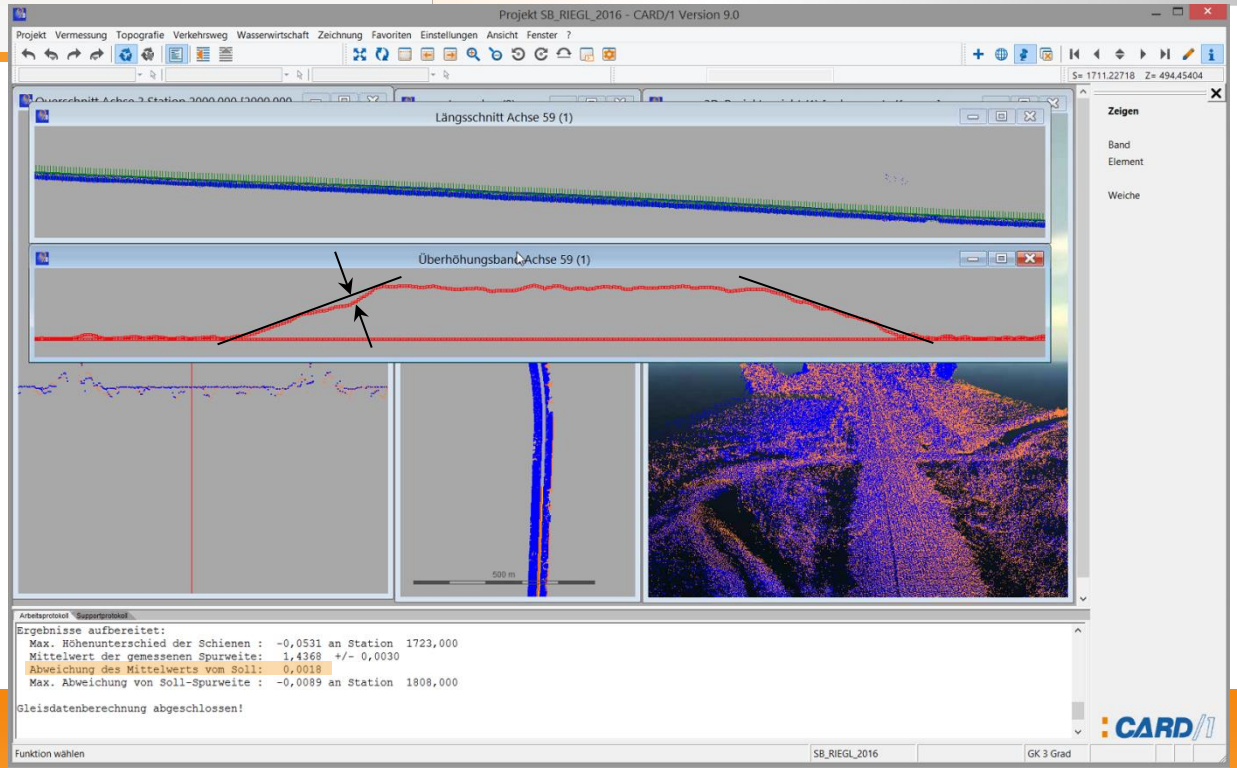



VMX-RAIL | accuracy evaluation

# Data Analysis

## Analysis of VMX-450 test dataset

- CARD/1 did a feasibility study of point cloud based railway track analysis
- Survey of the actual state of the track geometry shows deviations of superelevation to the planned state
- Gauge analysis showed 1.8 mm deviation to the planned state




VMX-RAIL | data analysis

# VMX Scan Pattern

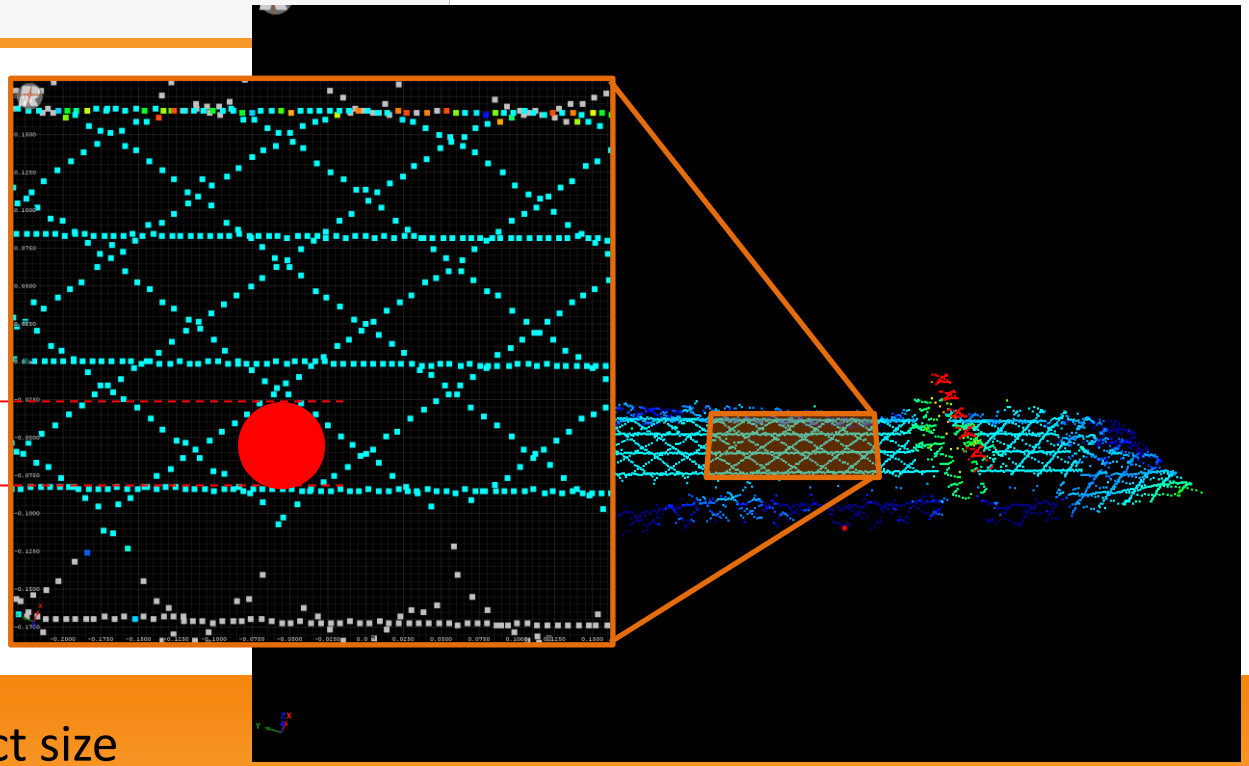
**critical flat object size @ 80 km/h**

80 km/h acquisition speed

line spacing 9 cm per scanner

critical **flat** object size of **5 cm**

detection of pole and wire objects with a few mm diameter

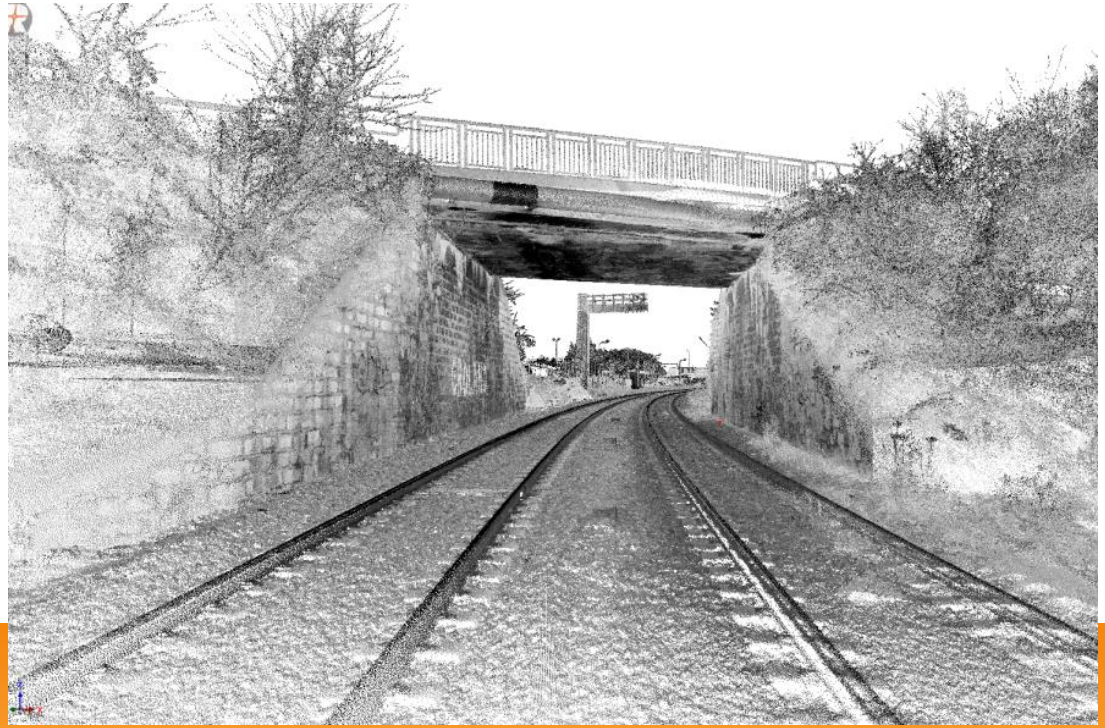


VMX-RAIL | critical object size

# VMX Scan Pattern

**Point cloud acquired with 30 km/h**

- achieve a very high level of detail
- capturing of very thin structures and small objects
- slow travel speed e.g. applicable in train stations

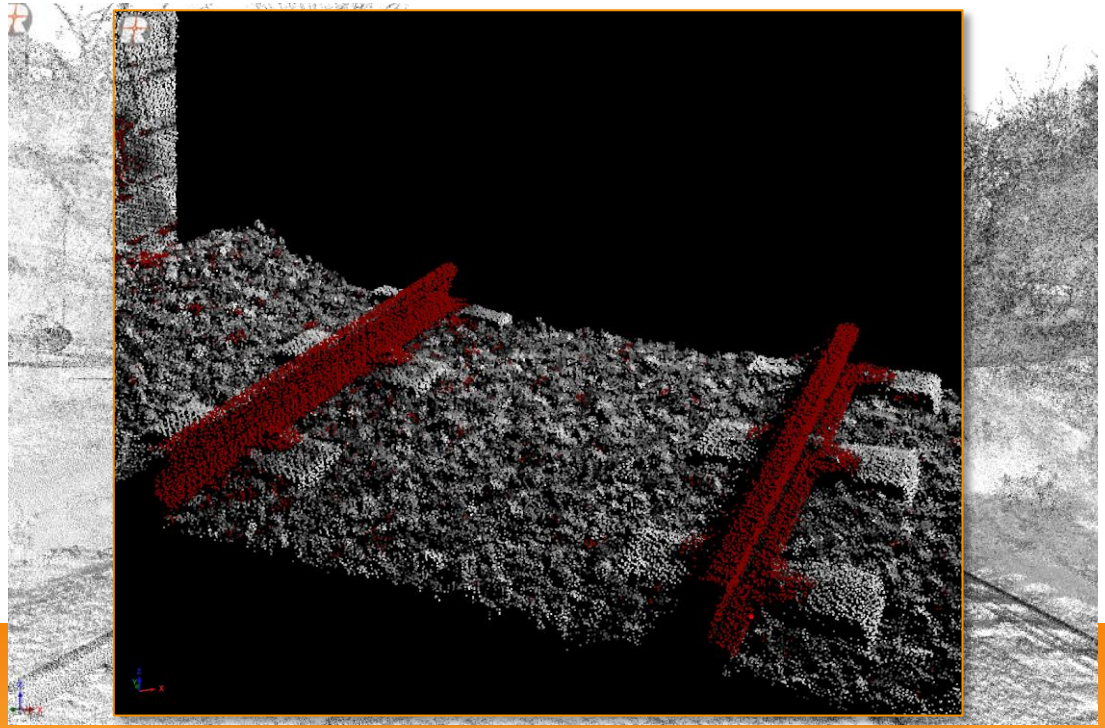


VMX-RAIL | point cloud pattern

# VMX Scan Pattern

**Point cloud acquired with 30 km/h**

- achieve a very high level of detail
- capturing of very thin structures and small objects
- slow travel speed e.g. applicable in train stations

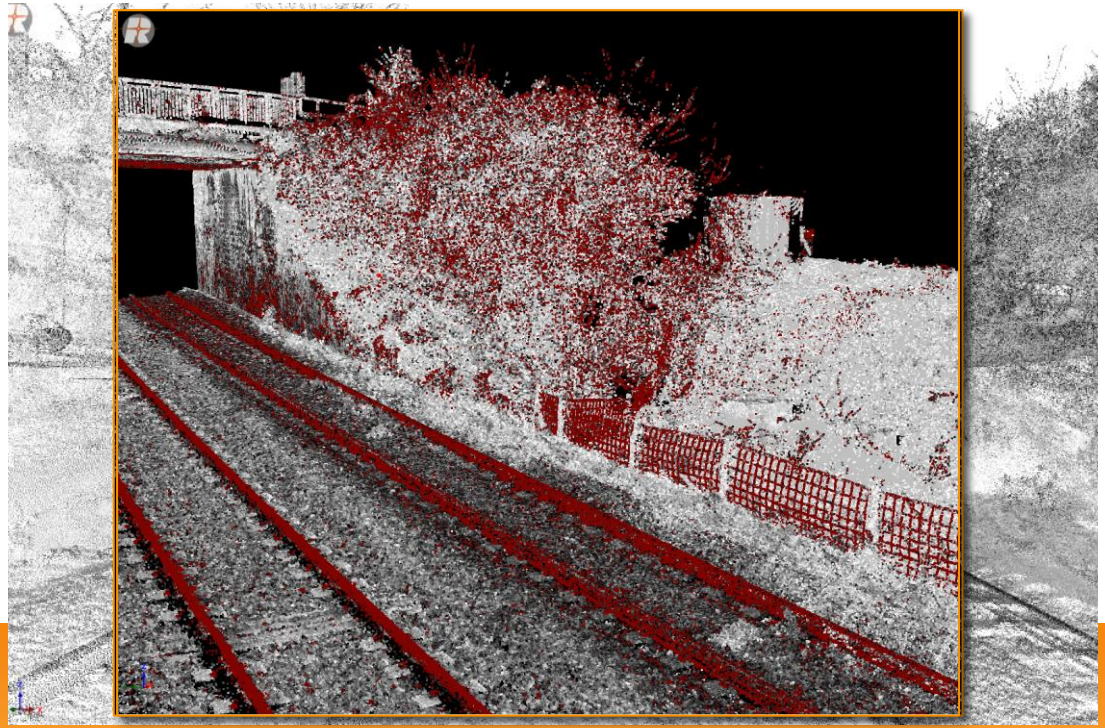


VMX-RAIL | point cloud pattern

# VMX Scan Pattern

**Point cloud acquired with 30 km/h**

- achieve a very high level of detail
- capturing of very thin structures and small objects
- slow travel speed e.g. applicable in train stations



VMX-RAIL | point cloud pattern

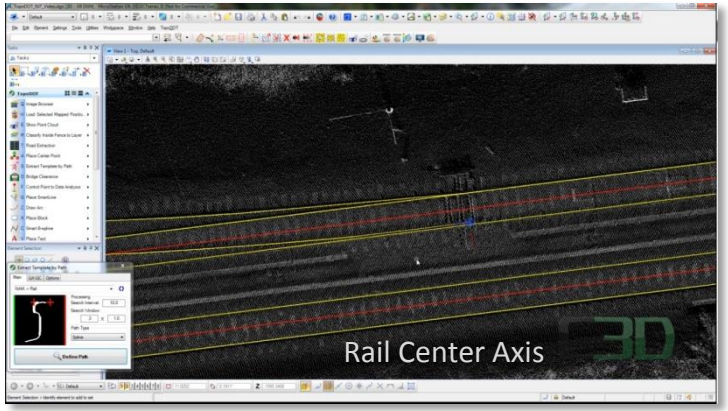
# Track Mapping & Clearance Surveying

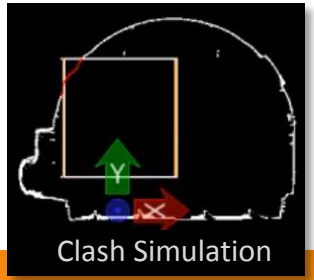
- enables the capture of the complete rail corridor, including
  - rail heads
  - catenary and catenary masts
  - overhead structures
  - ballast shoulders
  - signals
  - vegetation

## VMX-RAIL | application

# Track Mapping & Clearance Surveying

- enables the capture of the complete rail corridor, including
  - rail heads
  - catenary and catenary masts
  - overhead structures
  - ballast shoulders
  - signals
  - vegetation
- feature extraction with 3rd party software





## VMX-RAIL | application

# VMX-RAIL Key Features and Benefits

- reduction of scan shadows by multi-scanner system design
- rugged design for high durability in rough environmental conditions
- optionally customized roof mount for perfect integration with rail cars
- optimized on-site maintenance capabilities by modular measuring head setup
- rapid and safe data capture with minimal disruption to network schedules
- remote sensing avoids surveying staff to be exposed to any risks on railway tracks

# RiPRECISION

# RiPRECISION

**How does RIEGL deal with scan data misalignment?**

- even high-performance INS/GNSS is facing challenges in multipath environments and GNSS outage
- => trajectories have time-varying errors in all 6 DOF

**RiPRECISION**

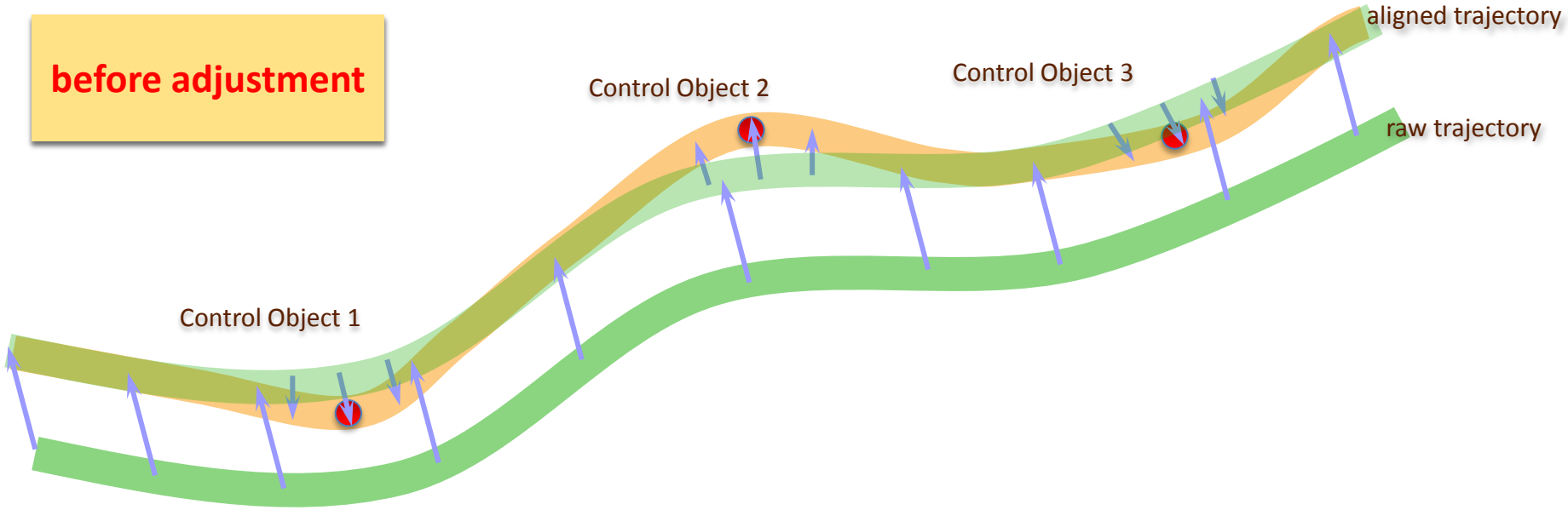
- takes external control (ground control points) **and auto-detected** features into account
- automated adjustment strategy enables efficient point cloud alignment
- fully embedded in *RIEGL's* kinematic data processing software

RiPRECISION | rigorous scan data alignment

RIEGL®

## RiPRECISION

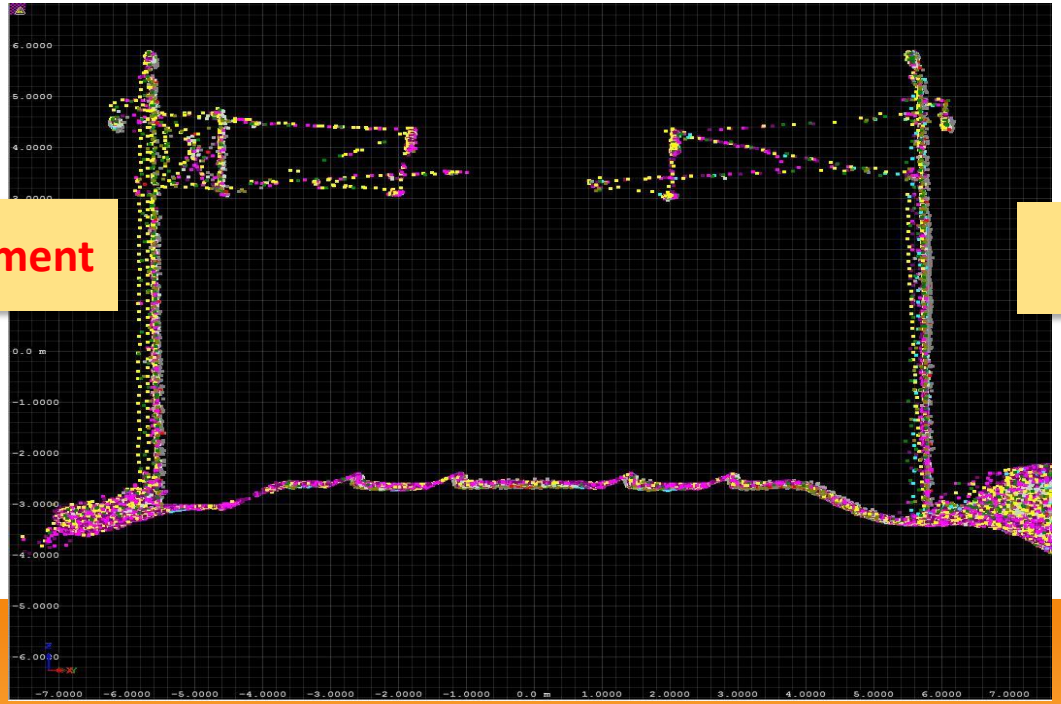
**before adjustment**




RiPRECISION | rigorous scan data alignment

# RiPRECISION

before adjustment




after adjustment

RiPRECISION

# the SNCF Réseau approach as case study of utmost efficiency

merging data acquired by different laser scanning disciplines

Mobile Laser Scanning

Unmanned Aerial Vehicle based Scanning

Terrestrial Laser Scanning

RIEGL®

## SNCF Réseau: VMX-450 and VMX-2HA

- SNCF Réseau **started MLS in 2013** with the first RIEGL VMX-450 on rail
- **30.000 km** scanned since 2013
- the system is used on a project basis
- => no permanent operation of the system

VMX | Application

RIEGL®

## SNCF Réseau: VMX-450 and VMX-2HA

- not used for periodic monitoring of the rail network
- local acquisition of high resolution surveys to increase level of detail compared to conventional point to point surveying
- recently SNCF Réseau is using also the **VMX-2HA** for project based surveys

VMX | Application

# SNCF Réseau: VMX-RAIL

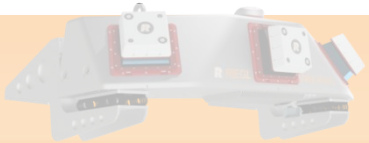
- SNCF Réseau is the **first user of RIEGL's VMX-RAIL** triple scanner system
- the goal: **periodic monitoring** of the rail network two times a year
- three trains are equipped with the VMX-RAIL
- **permanent operation** with planned system maintaining intervalls
- target for 2020: monitoring of **200.000 km** per year


## VMX | Application

# the SNCF Réseau approach as case study of utmost efficiency

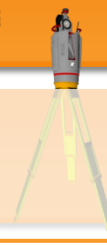
merging data acquired by different laser scanning disciplines

Mobile Laser Scanning



Unmanned Aerial Vehicle based Scanning

Terrestrial Laser Scanning



# RiCOPTER – Key facts

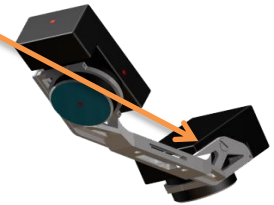
- Fully integrated turnkey solution
  - Octocopter
  - Foldable carrier arms
  - MTOM: <25 kg
  - max. 16 kg payload (batteries + sensor load)
  - up to 30 minutes endurance
  - Optimized for operation with *RIEGL* VUX-SYS

MLS and ULS | a perfect data complement

# RiCOPTER – Key facts

RIEGL VUX-SYS

Camera system



control unit
GPS receiver

inertial
meas. unit

RIEGL VUX-1

# Motivation for UAV

## Mobile Laser Scanning

**advantages**
- ✓ scanning of several 100 km per day
- ✓ high details of corridor infrastructure
- ✓ system position and field of view optimized for
  - clearance analysis
  - asset detection

**challenges**
- ✓ objects and togography far away from the rail track can not be captured
- ✓ acquisition times need to be scheduled long time in advance

## Unmanned Laser Scanning

**advantages**
- ✓ quick deployment
- ✓ flexibility of vantage point
  - possibility to scan rail infrastructure and
  - surrounding area
  - roof tops
  - facades

**challenges**
- ✓ limited operation time / limited area performance
- ✓ flight permission limitations

MLS and ULS | a perfect data complement

# Motivation for UAV

Mobile Laser Scanning

Unmanned Laser Scanning

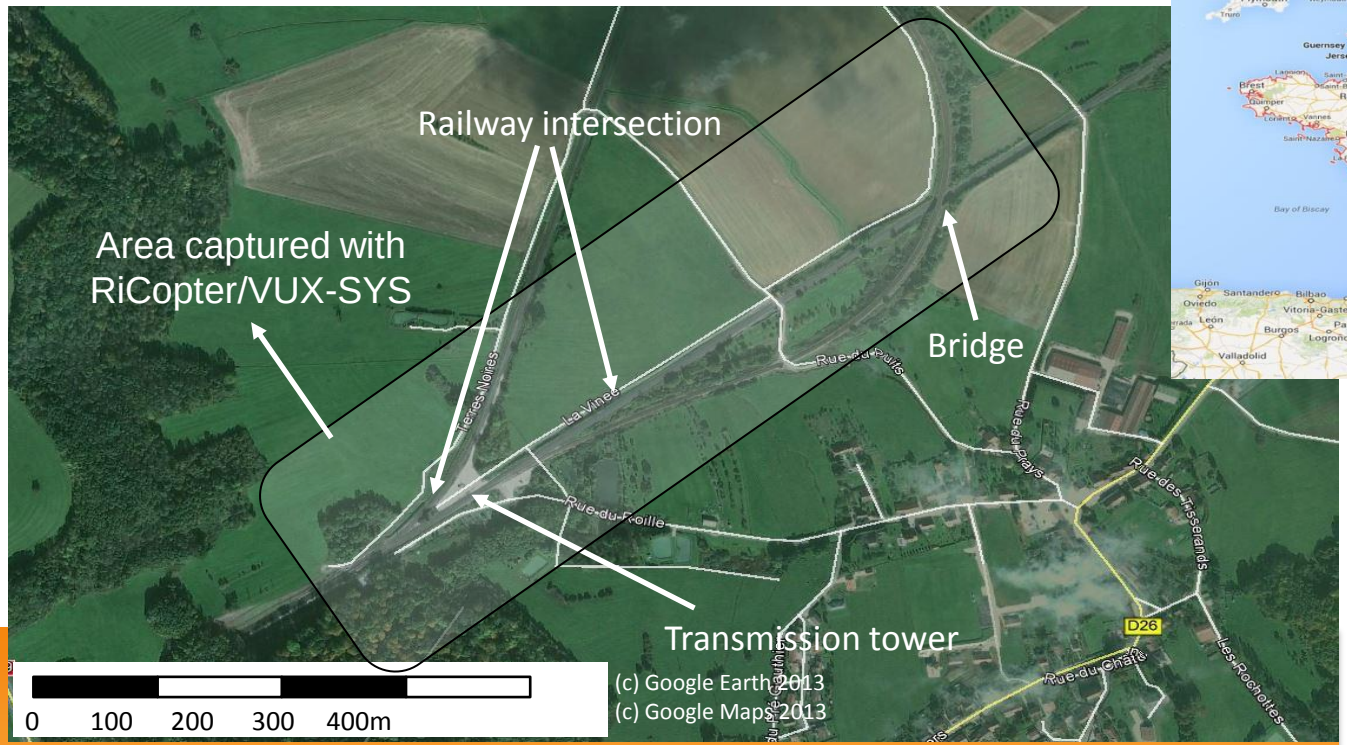
## benefits from combining MLS and ULS

- both technologies face different challenges but have complementary strength
- MLS and ULS complement each other perfectly
- combining ULS and MLS **improves the balance between coverage and level of detail**
- easy data merging of MLS and ULS projects
- joint registration and data alignment for MLS and ULS

MLS and ULS | a perfect data complement

RIEGL®

# Project Overview

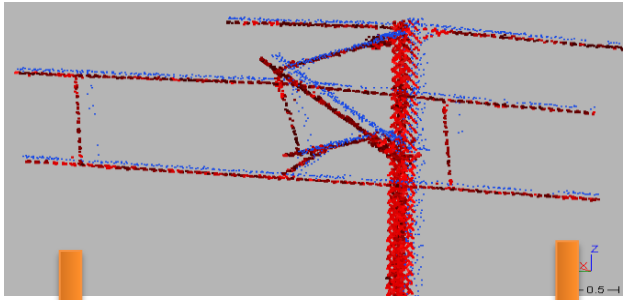



## Precision and accuracy

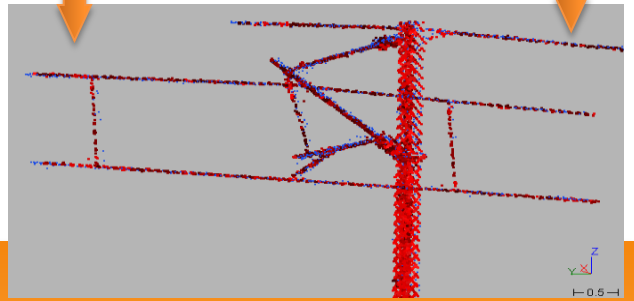
**Mobile LiDAR** mounted on a rail car vs. **UAV LiDAR**

- Point density rail head
  - UAV: 1 meter track length => More than 30 points @ 30 km/h
  - MLS: 1 meter track length => more than 600 points @ 75 km/h
- Points per m2
  - UAV: 200 pts @ 50 m flight altitude @ 30km/h
  - MLS: 4000 pts @ 75 km/h in 6 meter range
- Point cloud geometry
  - UAV LiDAR perfectly fitting with Mobile LiDAR point cloud

*offset before alignment*



*offset after alignment*



MLS and ULS | a perfect data complement

## UAV Sample Data

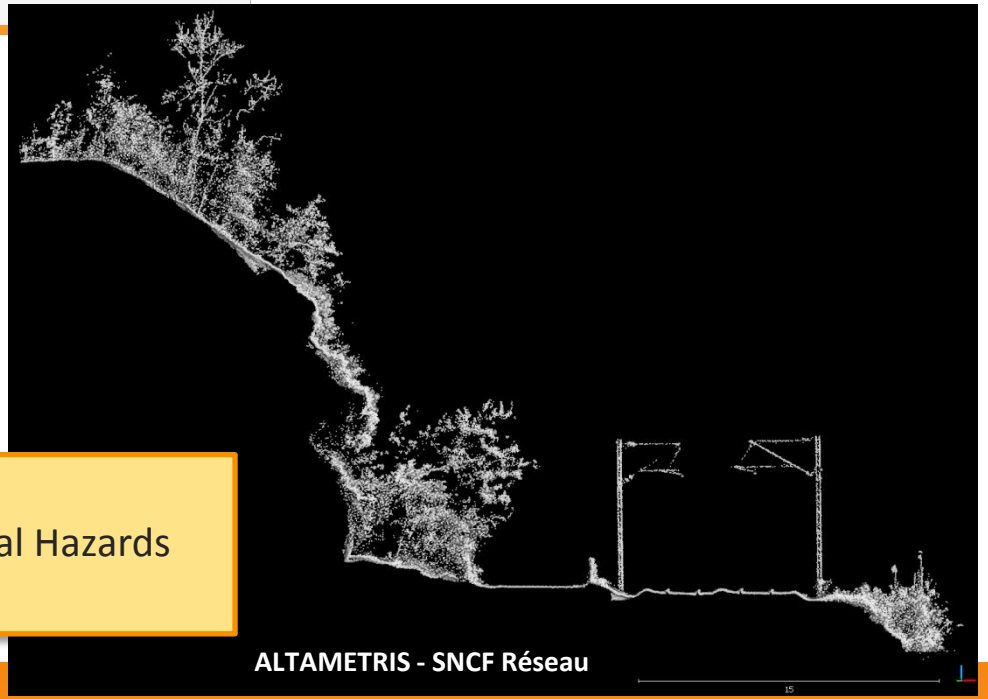
- some impressions of rail infrastructure captured by UAV based scanning
- MLS: high level of detail on rail track
- ULS: complete surrounding assets


**MLS:** high resolution rail track
**MLS:** GNSS denied acquisition in the tunnel
**ULS:** rail track + surrounding topography

MLS and ULS | a perfect data complement

## UAV Sample Data

- some impressions of rail infrastructure captured by UAV based scanning
- MLS: high level of detail on rail track
- ULS: complete surrounding assets

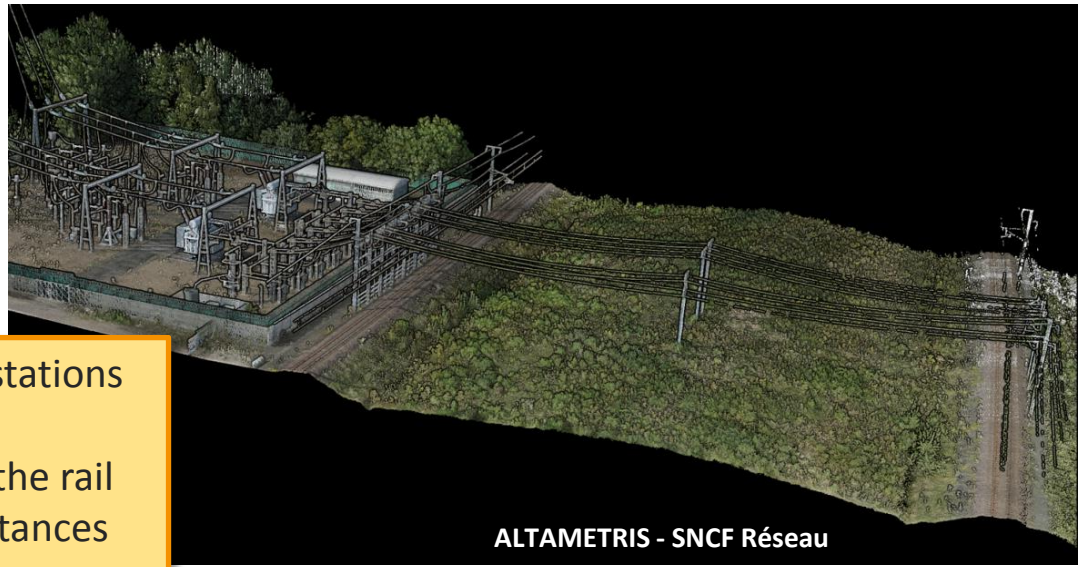



detailed cross sections
documentation and investigation of Natural Hazards
planning of hazard prevention measures

MLS and ULS | a perfect data complement

# UAV Sample Data

- some impressions of rail infrastructure captured by UAV based scanning
- MLS: high level of detail on rail track
- ULS: complete surrounding assets



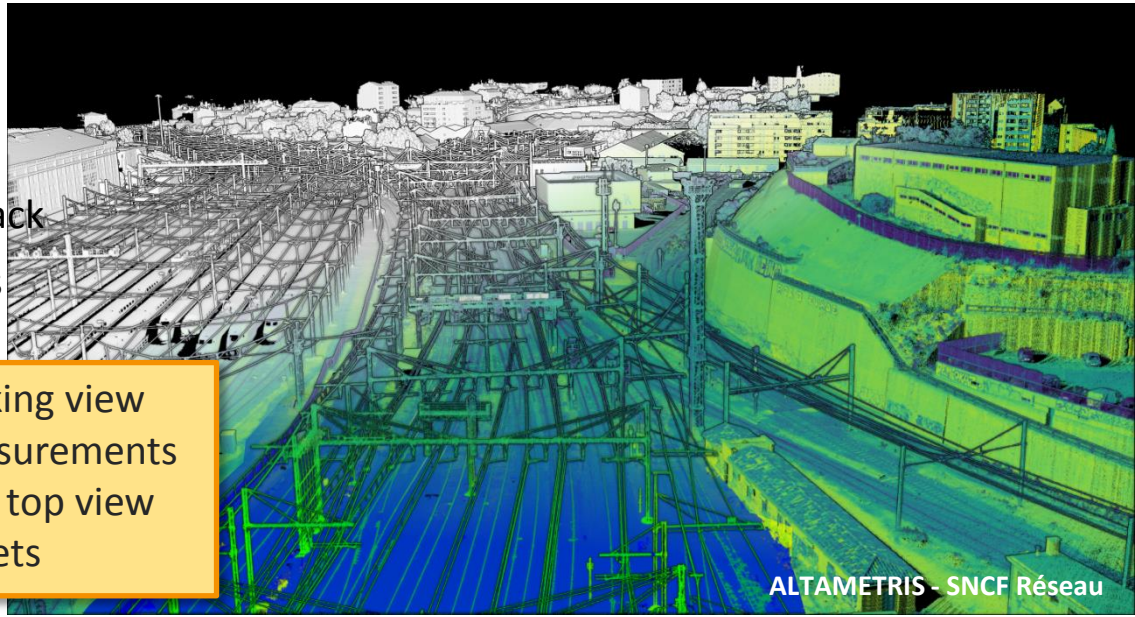

**ULS:** asset management of transformer stations and corridor mapping
**MLS:** inspection of infrastructure along the rail track with high speed over long distances

## MLS and ULS | a perfect data complement

RIEGL®

## UAV Sample Data

- some impressions of rail infrastructure captured by UAV based scanning
- MLS: high level of detail on rail track
- ULS: complete surrounding assets




**MLS:** get structures from upward looking view
get dense rail and catenary measurements
**ULS:** get overpasses and bridges from top view
get surronding buildings and assets

MLS and ULS | a perfect data complement

## the SNCF Réseau approach as case study of utmost efficiency

merging data acquired by different laser scanning disciplines

Mobile Laser Scanning

Unmanned Aerial Vehicle based Scanning

Terrestrial Laser Scanning

# Motivation for UAV

## Mobile Laser Scanning

**advantages**
- ✓ scanning of several 100 km per day
- ✓ high details of corridor infrastructure
- ✓ system position and field of view optimized for
  - clearance analysis
  - asset detection

**challenges**
- ✓ objects and togography far away from the rail track can not be captured
- ✓ acquisition times needs to be scheduled long time in advance

## Terrestrial Laser Scanning

**advantages**
- ✓ ultra high resolution
- ✓ automated registration of multiple scan positions
- ✓ very high accuracy
- ✓ absolute accuracy is not affected by trajectory
- ✓ quick deployment
- ✓ very efficient for small, complex areas e.g. railway stations, platforms, railway crossings

**challenges**
- ✓ safety measures for operator when operting on danger areas, etc…
- ✓ not suited for wide area track mapping

MLS and ULS | a perfect data complement

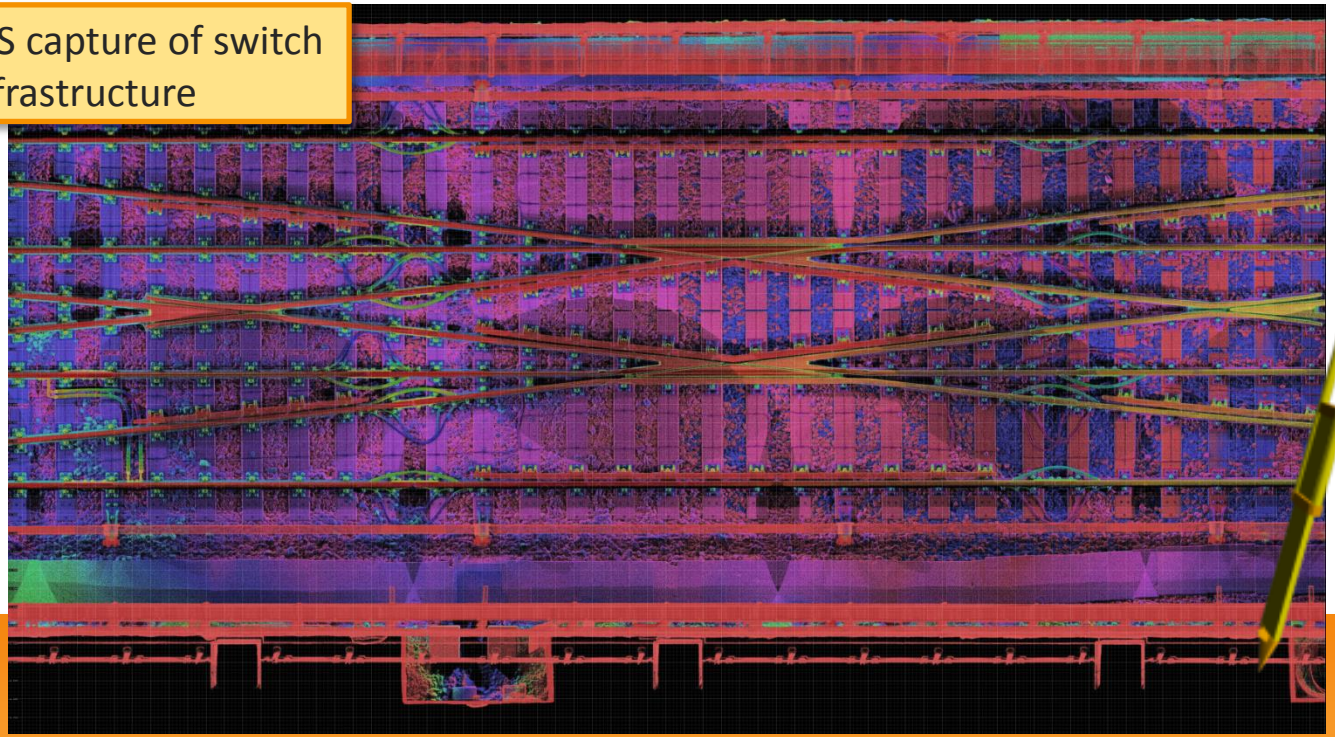
# SNCF: TLS use in rail application

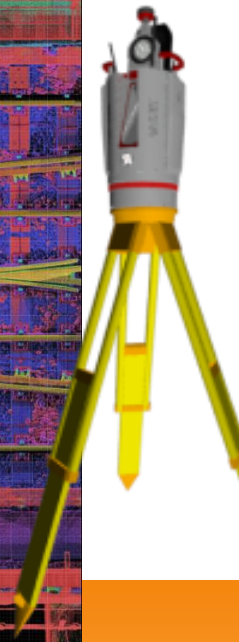
- SNCF Réseau uses TLS as complement to MLS
- VZ-400i (1000 m range) is used for small scale projects
  - train stations
  - building sites
- efficiency with VZ-400i **5-times** higher compared to traditional methods

MLS and TLS | a perfect data complement

# TLS sample data of switch

high resolution TLS capture of switch and surronding infrastructure





MLS and TLS |

# Customer Project: Temporary GNSS Denied Area

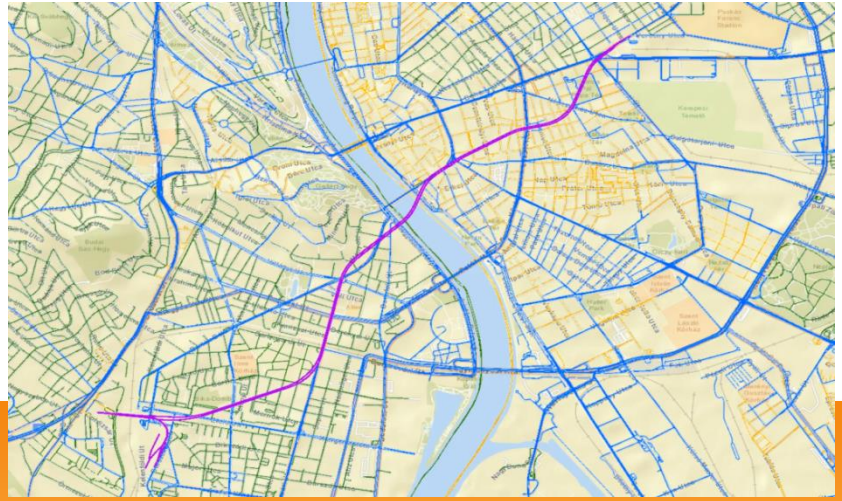
## Scanning of Subway Lines via Rail Cars

POC: Gyula Szabolcs FEKETE,
Senior GIS expert,
gyula.fekete@budapestkozut.hu
Company: Budapest Közút Zrt.

Customer Projects

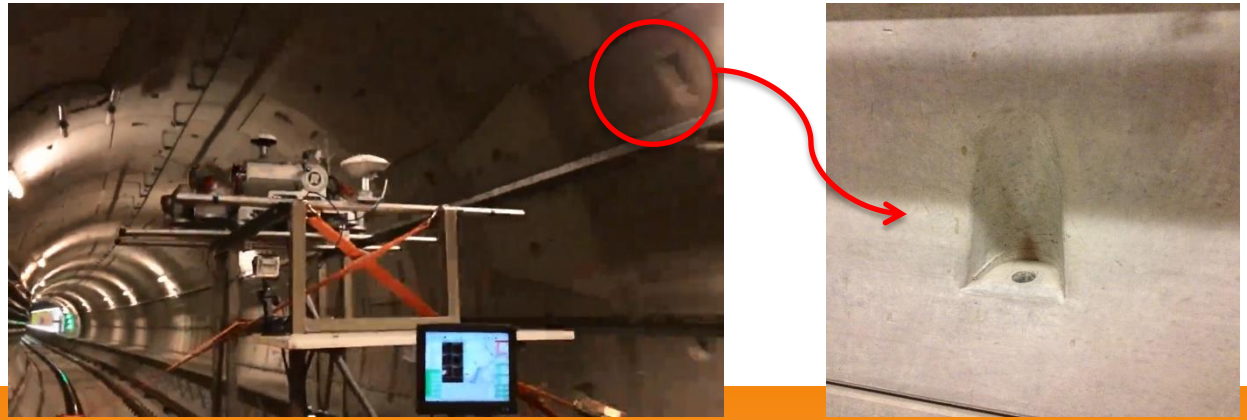
## Project Requirements

- scanning of new dead-end Metro Line M4 in Budapest > 7.5 km length
- availability of GNSS for initial and final static and dynamic alignment
- 45 minutes data acquisition in GNSS denied subway area

## Project Requirements

- data acquisition can be performed only in night shifts
- limited time window of 6 hours to acquire the full dataset
- very dense GCP spacing available (25 meter) for evaluation



Customer Projects

# Accuracy Evaluation

- final accuracy after PosFix + RiPRECISION
  100 m GCP spacing

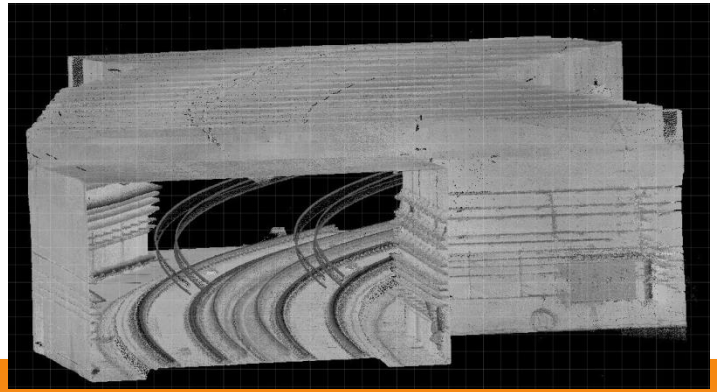
| | |
|---|---|
| Minimum distance | 0.004 m |
| Maximum distance | 0.187 m |
| Average | 0.047 m |
| RMSE | 0.037 m |

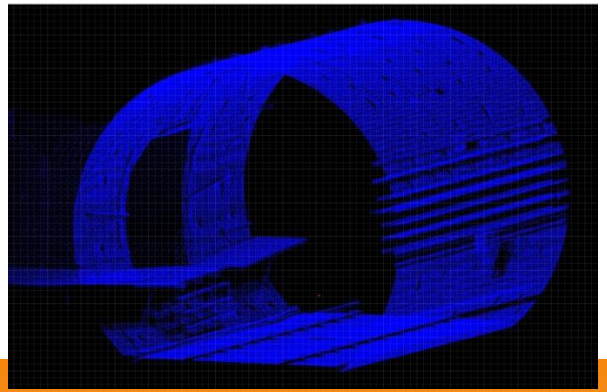
- final accuracy after PosFix + RiPRECISION
  25 m GCP spacing

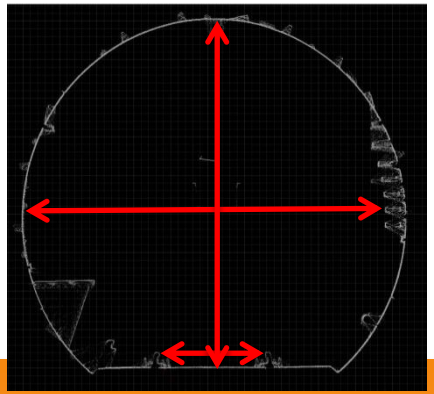
| | |
|---|---|
| Minimum distance | 0 m |
| Maximum distance | 0.05 m |
| Average | 0.013 m |
| RMSE | 0.007 m |

# Metro Budapest

- high relative accuracy enables precise
  - measuring of cross section dimensions
  - clearance analysis
  - detection of objects and inventory assets







Customer Projects

# Customer Project: MASER Consulting, P.A.

## Underground Tunnel Mapping

Clay Wygant, PLS
cwygant@maserconsulting.com
505-228-3154

Customer Projects

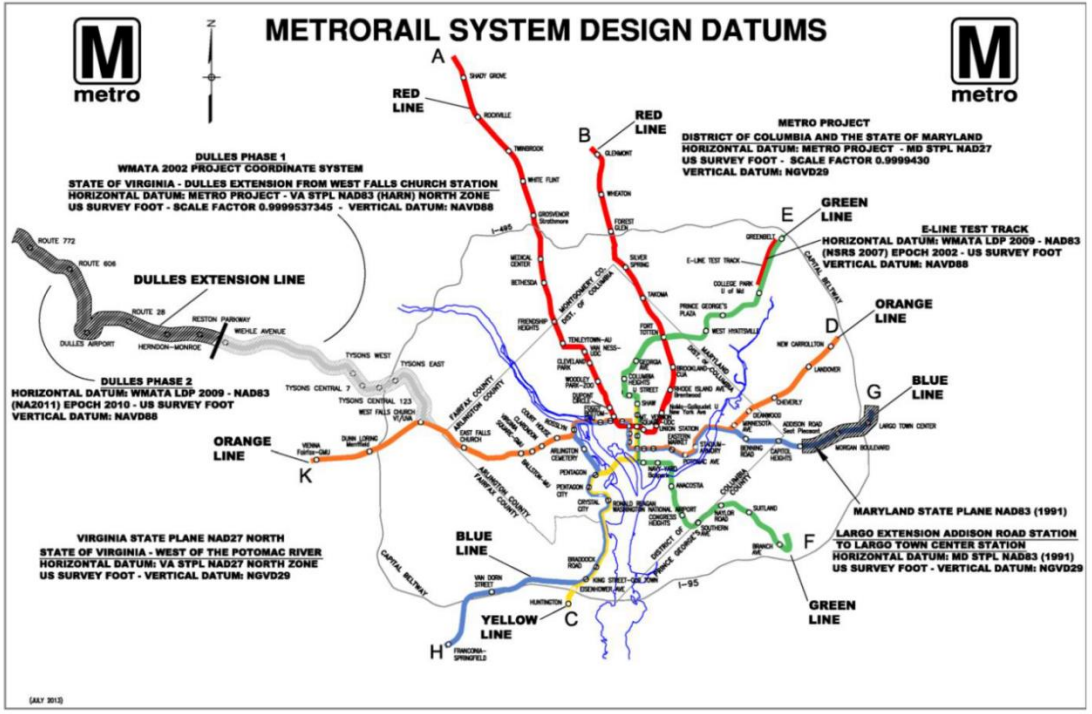
# The Mission

## The Goal

- Acquisition of LiDAR as-built for 160 km of tunnel
- Develop cable length for leaky coax communication

## The Challenge

- Metro scan in GNSS denied environment




Customer Projects

## The Challenges

### Data collection

- collect LiDAR for long segments of tunnel with limited to no GPS coverage
- adjust the collected LiDAR and imagery to a variety of design datums
- maintain 0.3m of absolute geodetic accuracy

Customer Projects

## Project Output

### Produce Deliverables

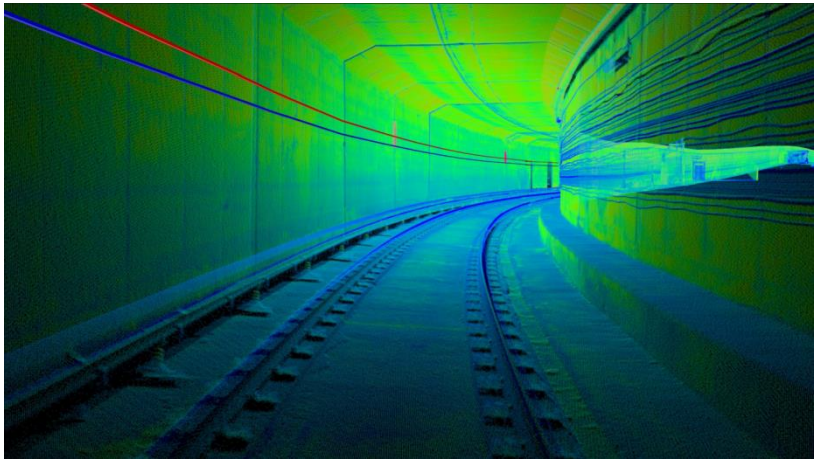
- cloud-based delivery of system-wide LiDAR
- to support the development of a new communications system (cellular & system)
- check clearances of design location of new leaky coax cables
- optimized planning of new cabling

Customer Projects

## Project Output

### Produce Deliverables

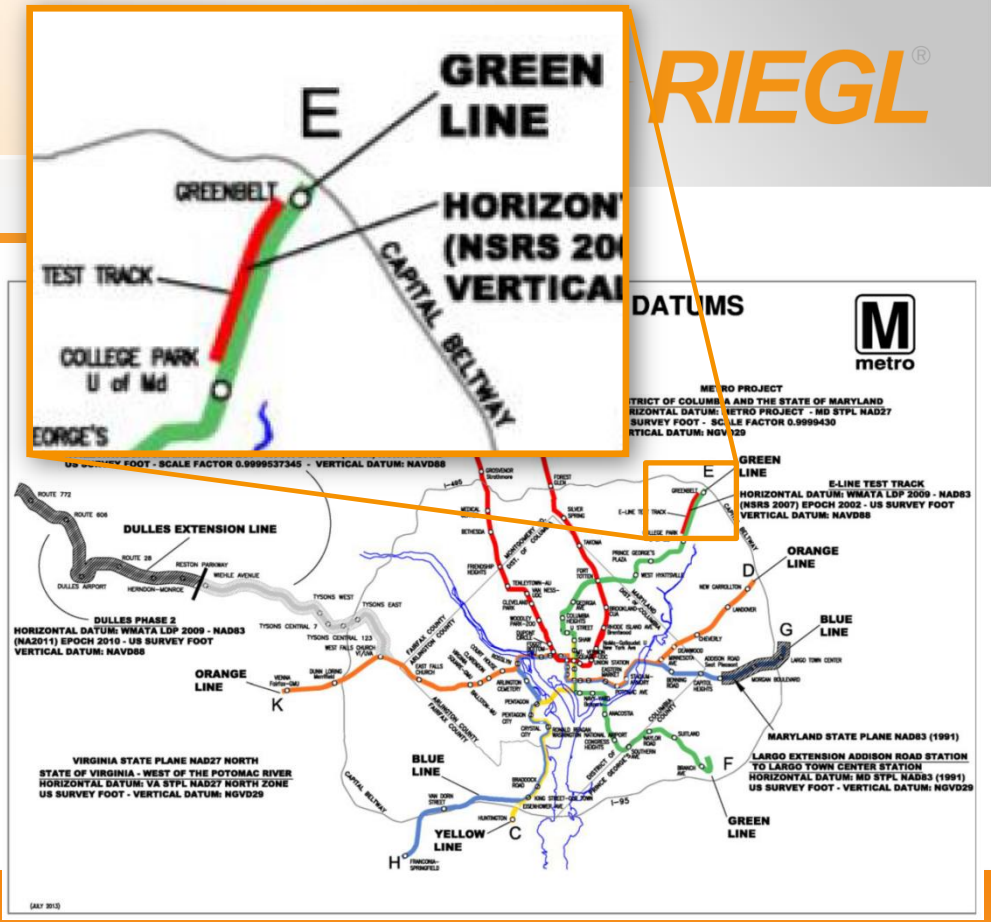
- use ground control for data adjustment
- extract track geometry from point cloud
- accuracy verification by independent authority based on hard survey
- output the LiDAR & Imagery to the cloud
- lay in cable in 3D space and check clearances



Customer Projects

## Project Output

- optimization of cable length could be proven in a feasibility study
- reduction of 4000m cable length in the small test area
- high potential for optimizing cabling costs in the full metro network
- **reduction of construction costs by using LiDAR technology for planning**




Customer Projects

# Thank you
# for your kind attention!






Innovation in 3D