Autonomous vehicle-track interaction monitoring and railway infrastructure maintenance

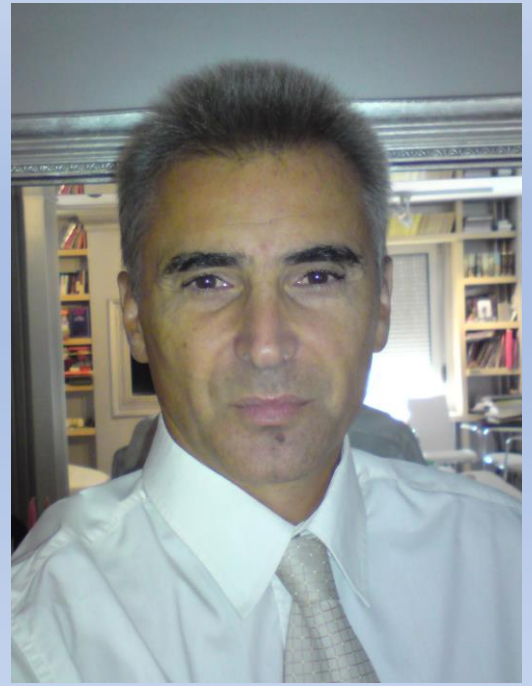
Prof. **Stasha Jovanovic**, Ph.D.
Faculty of Technical Sciences, Novi Sad, Serbia & Ensco Inc., Springfield, USA

Predrag Tešić, M.Sc. Civ. Eng., Tangram projekt d.o.o., Novi Sad, Serbia

Matthew Dick, Ensco Inc., Springfield, USA

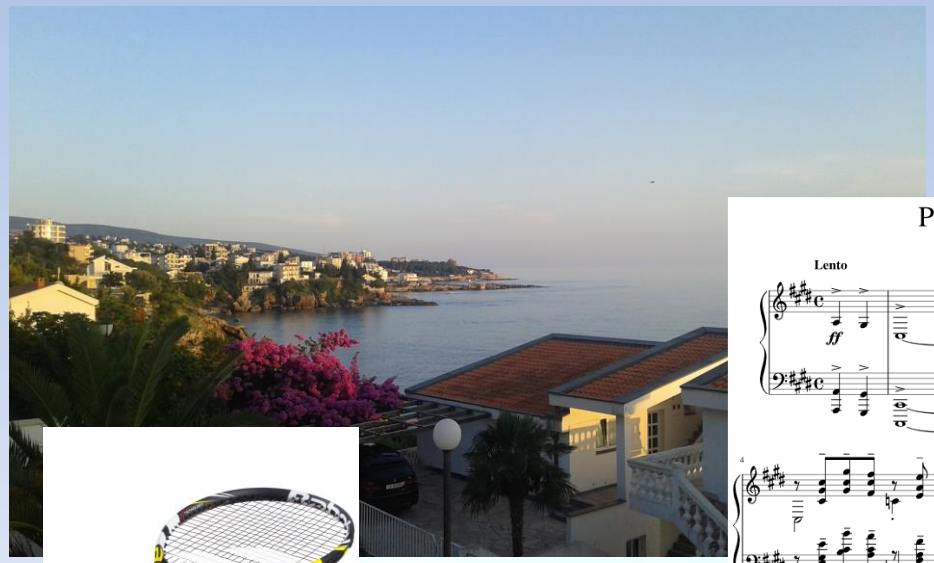
stasha.jovanovic@gmail.com

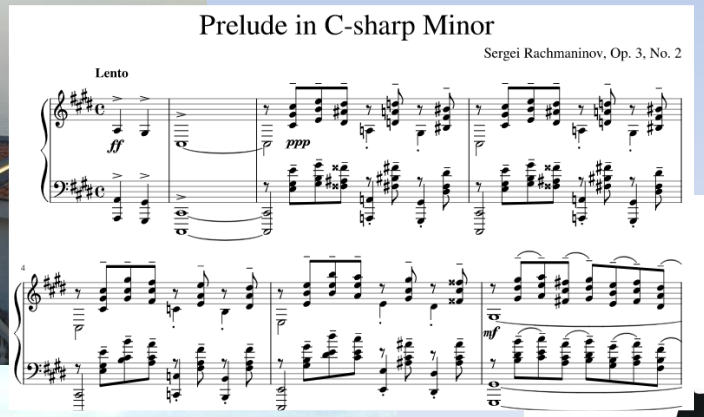
ICRI Webinar - 09 December 2020

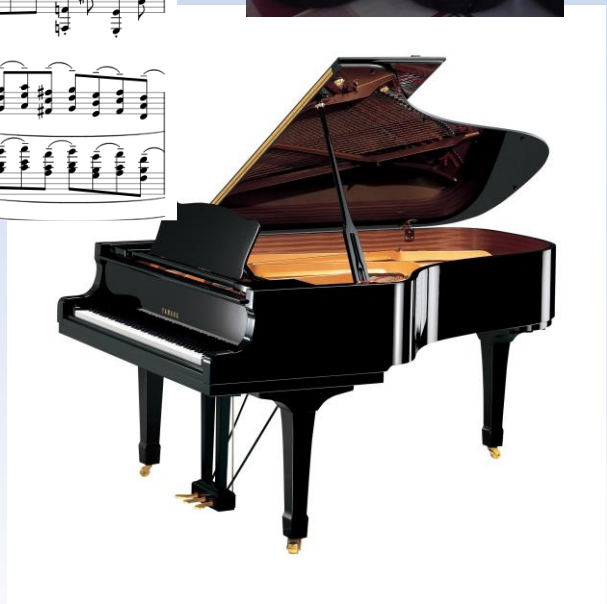


Autonomous vehicle-track interaction monitoring and railway infrastructure maintenance

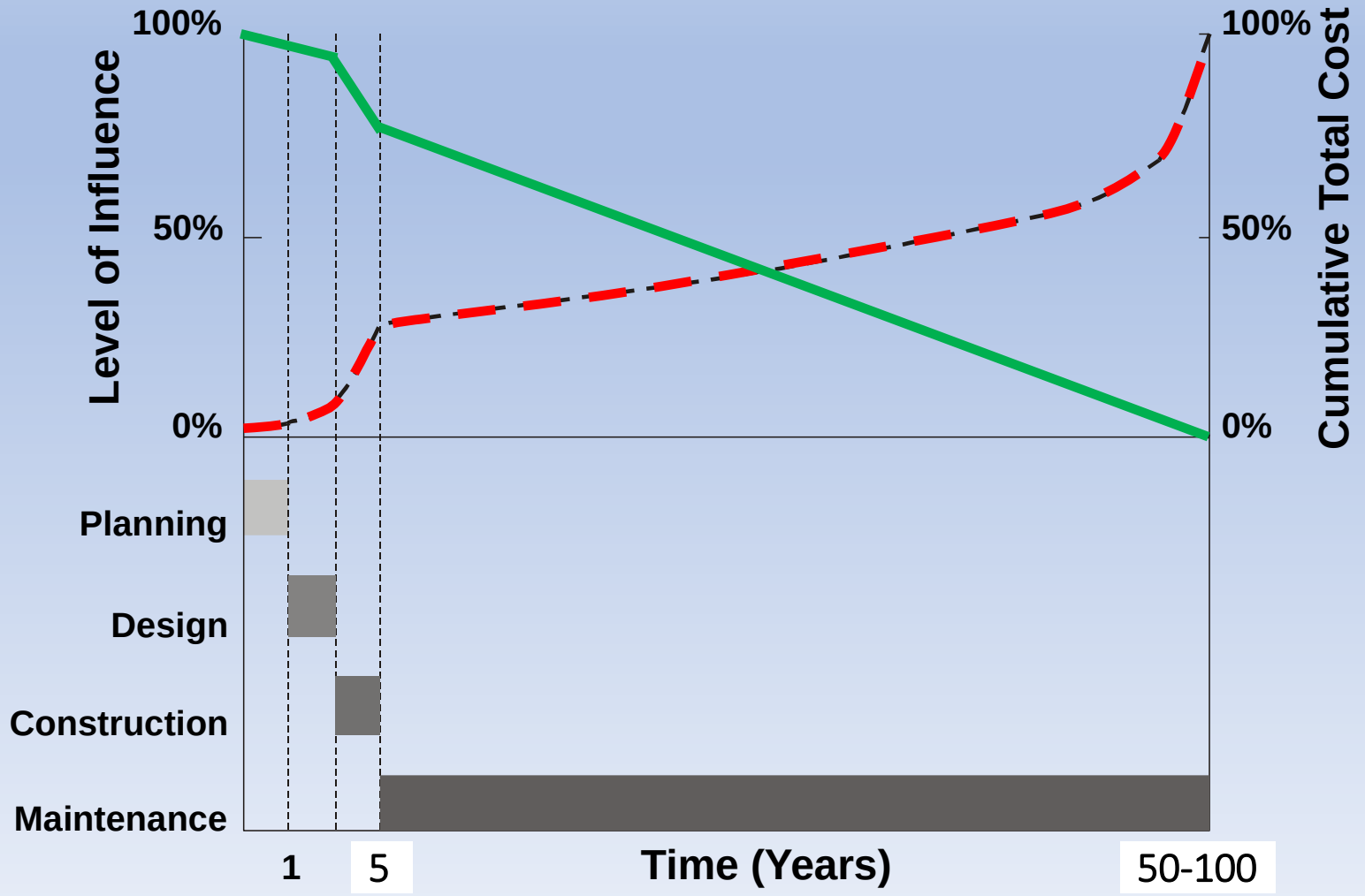
Stasha Jovanovic
Associate Professor, Faculty of Technical Sciences, Novi Sad, Serbia
&
Senior Advisor, Ensco Inc., Springfield, USA





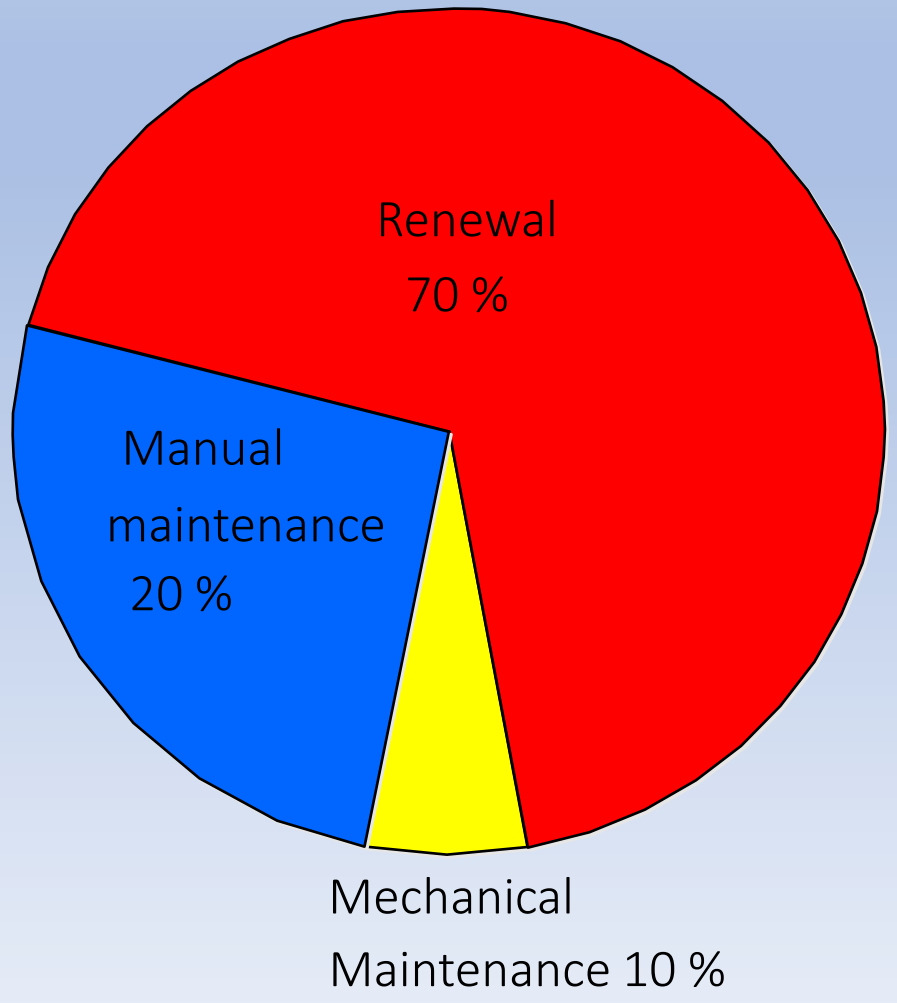


Importance of infrastructure maintenance



stasha.jovanovic@gmail.com

Costs of Track maintenance



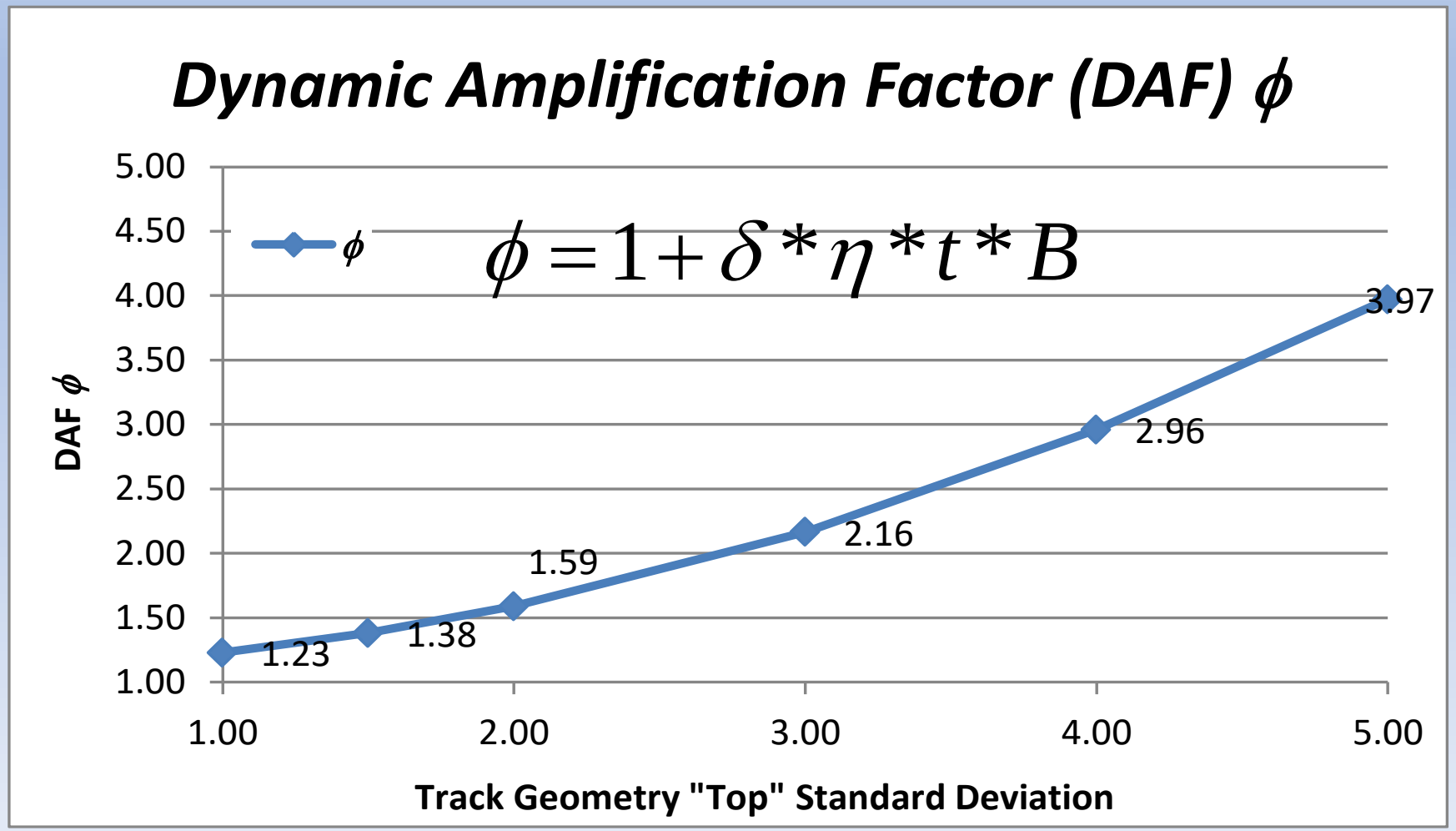
TOTAL MAINTENANCE AND RENEWAL COST on Dutch Railway network (ProRail) (Esveld)

€ 250 million per year
for 4.500 km track
Price level 2006

Average in Western Europe:
≈ 50,000 EUR/km/year
on conventional lines

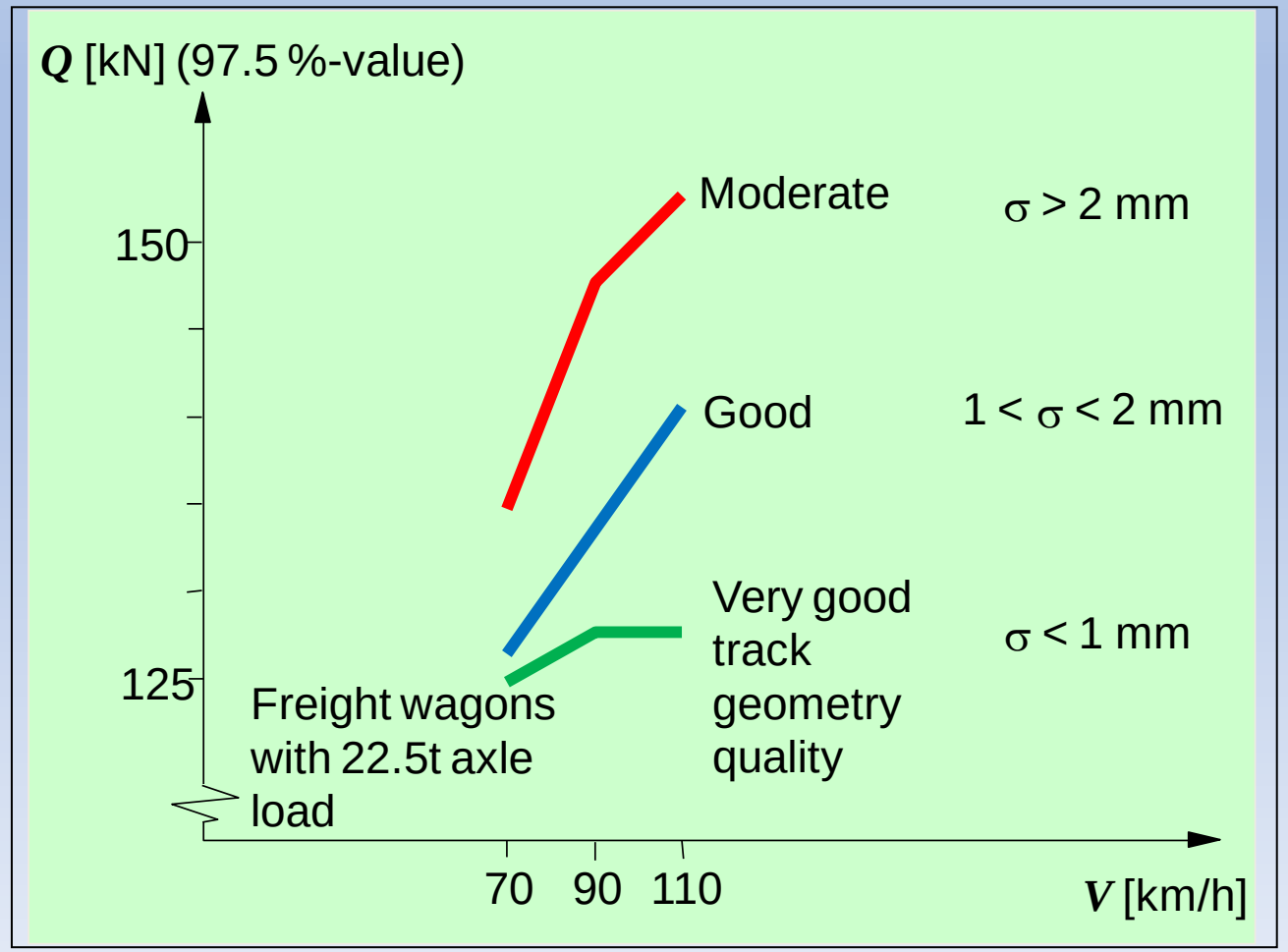
stasha.jovanovic@gmail.com

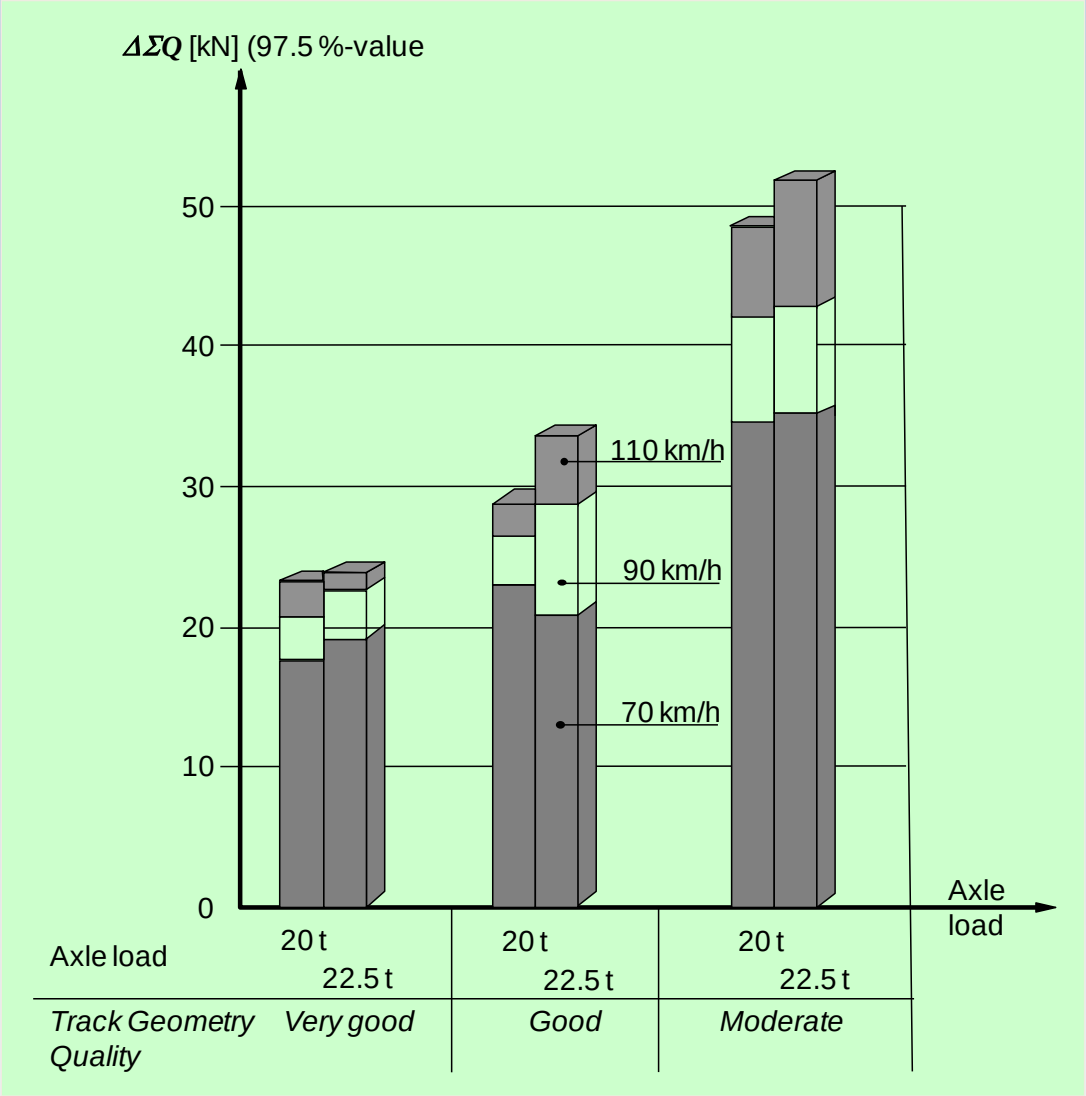
Influence of track geometry quality



stasha.jovanovic@gmail.com

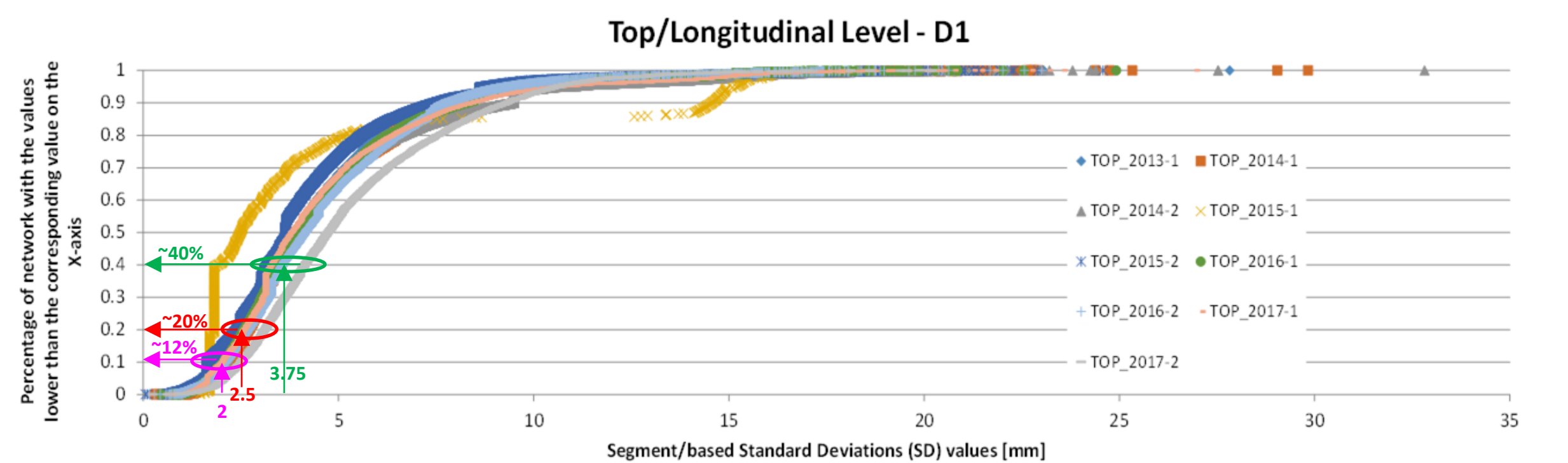
Influence of track geometry quality





stasha.jovanovic@gmail.com

Influence of track geometry quality



Speed [km/h]	Limit value of Standard Deviation [mm]				
	Track Quality Classes				
	A	B	C	D	E
V ≤ 80	< 1.25	1.75	2.75	3.75	> 3.75
80 < V ≤ 120	< 0.75	1.10	1.80	2.50	> 2.50
120 < V ≤ 160	< 0.65	0.85	1.40	1.85	> 1.85

Track Geometry (Standard Deviations - SD):

Track Quality EN 13848

stasha.jovanovic@gmail.com

M&R Costs Estimation Model

ORE/ERRI D141 & D161.1 Research Projects

Deterioration "Law", which is characteristic for every element and every type of a track structure, depends on the traffic characteristics:

$$E = k * T^{\alpha} * P^{\beta} * V^{\gamma}$$

where:

E **– TG deterioration (E = e(T) - e0)**

k **– Coefficient adherent to particular circumstances at a certain railway**

T **– Accumulated Traffic Load (Dynamic)**

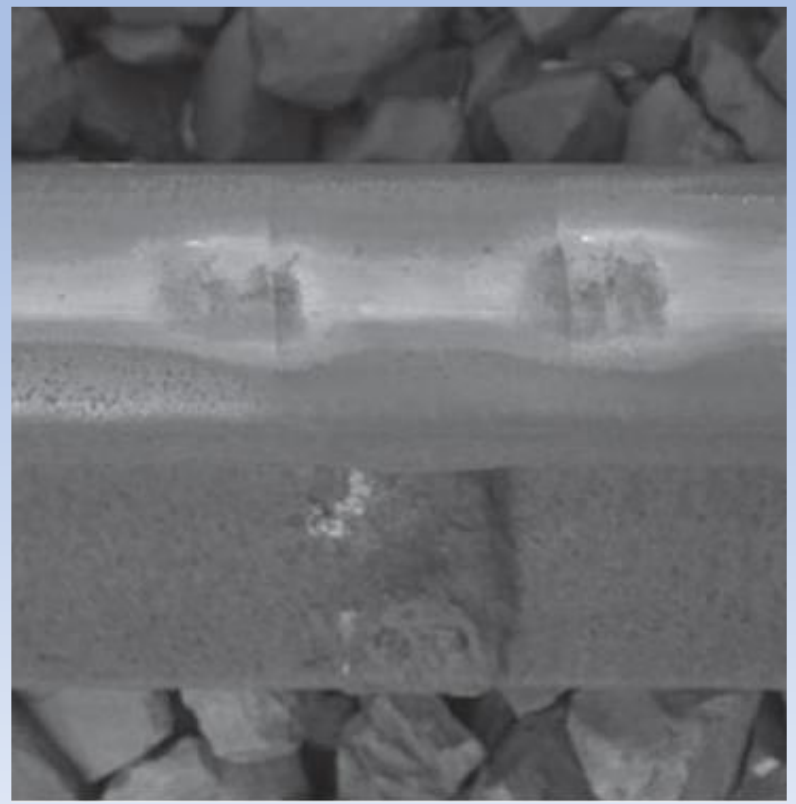
P **– Representative Axle Load**

V **– Train speeds**

while the exponents α, β and γ represent empirically established constants, pertaining to different aspects of track deterioration (such as: rail fatigue, rail surface defects, fatigue of other components, track geometry deterioration) and carry different corresponding values, accordingly.

stasha.jovanovic@gmail.com

Other important factors causing increase in dynamic forces



Left - ***mechanical rail joint***; middle & right – bad quality (battered) ***rail weld***

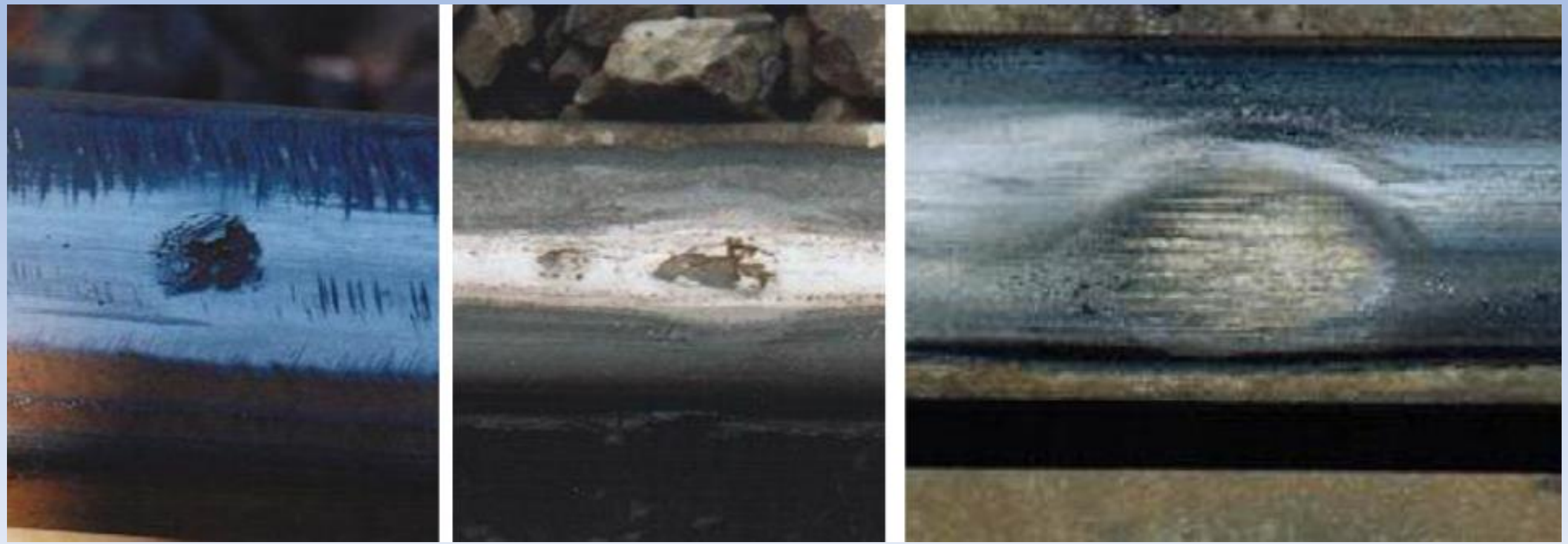
stasha.jovanovic@gmail.com

Other important factors causing increase in dynamic forces

Left – starting/lighter form of a ***squat*** defect; right – more severe form of a squat defect

stasha.jovanovic@gmail.com

Other important factors causing increase in dynamic forces



Wheel-burns, small (left), medium (middle) and severe (right)

stasha.jovanovic@gmail.com

Other important factors causing increase in dynamic forces

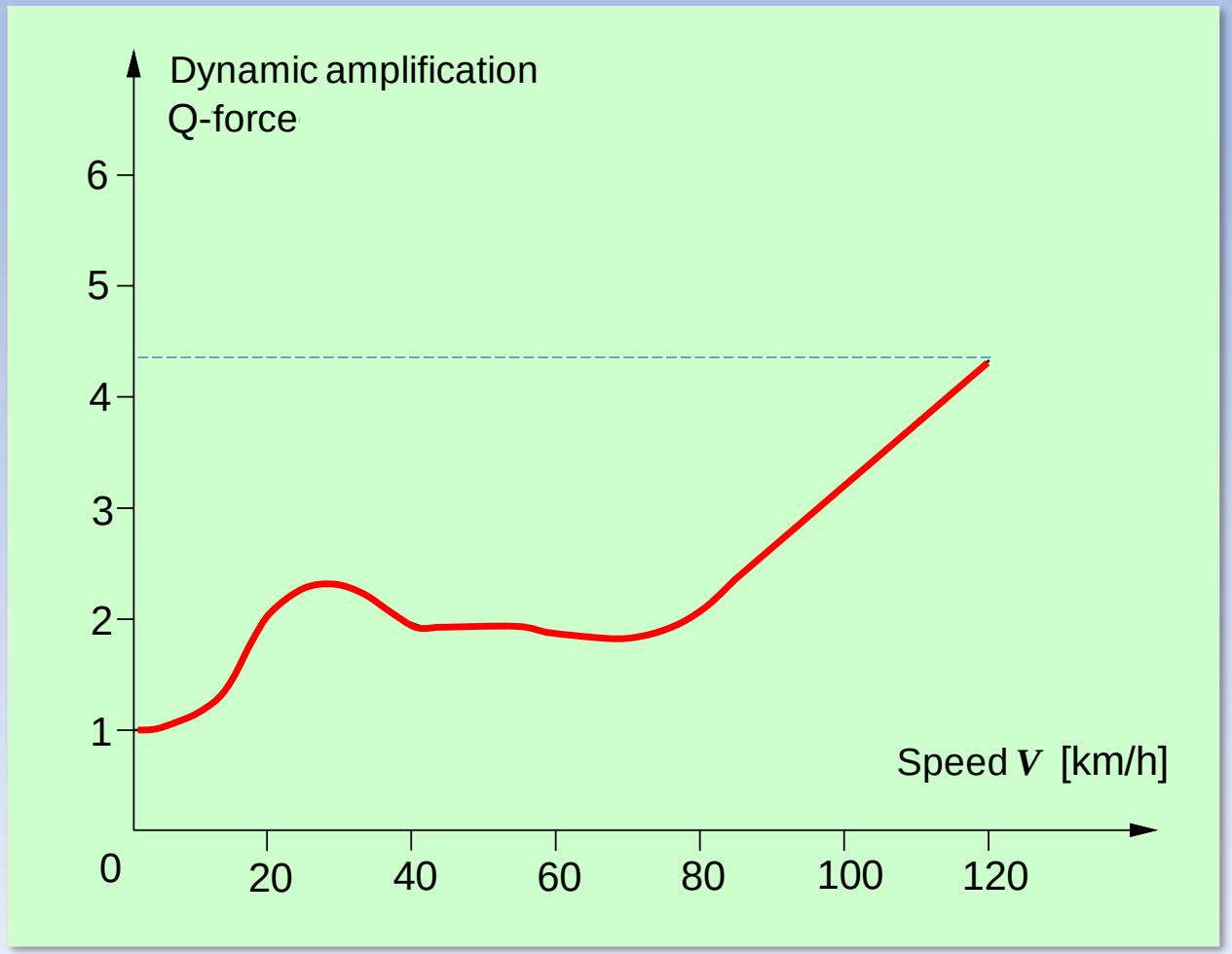
Rail corrugation

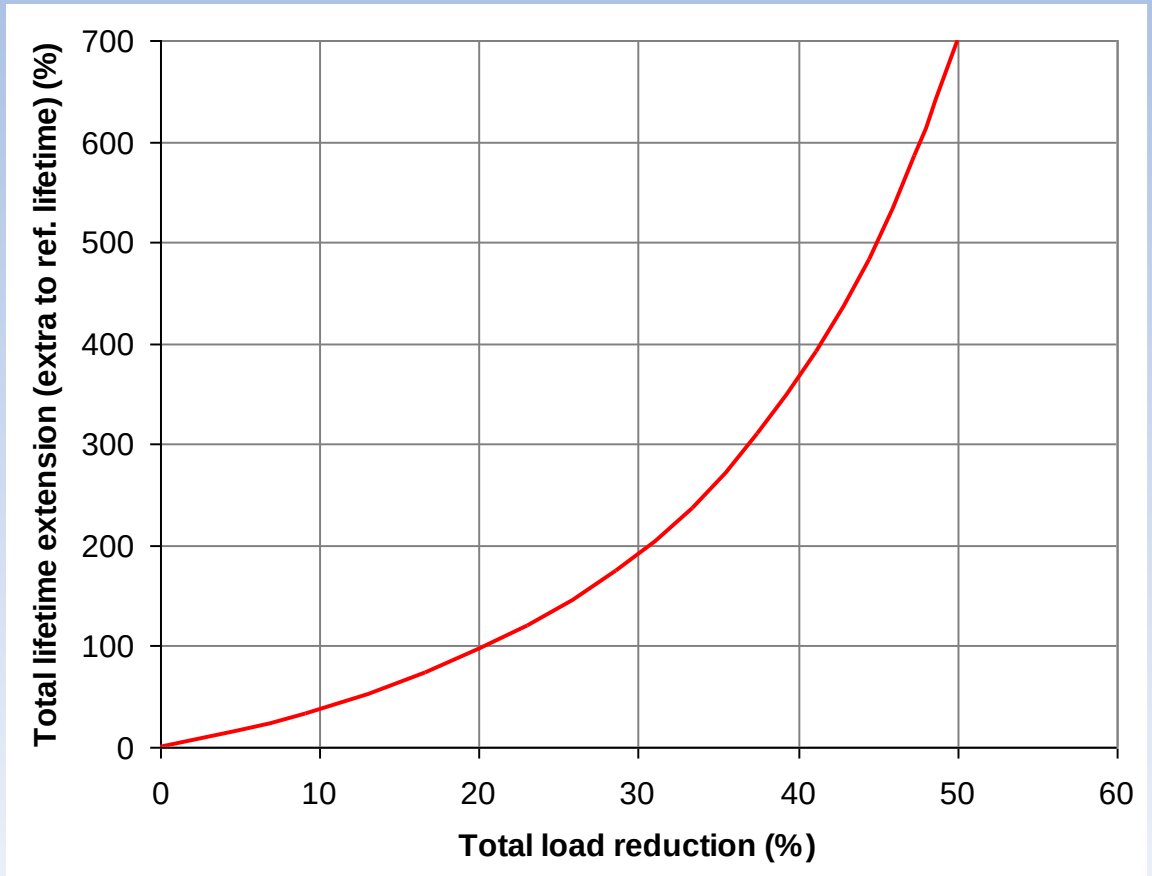
stasha.jovanovic@gmail.com

Influence of rail welds quality

$$\frac{LifeTime_{New}}{LifeTime_{Reference}} = \left(\frac{F_{Reference}}{F_{New}}\right)^3$$

$$F_{wheel} = F_{wheel,static} + F_{wheel,dynamic}$$





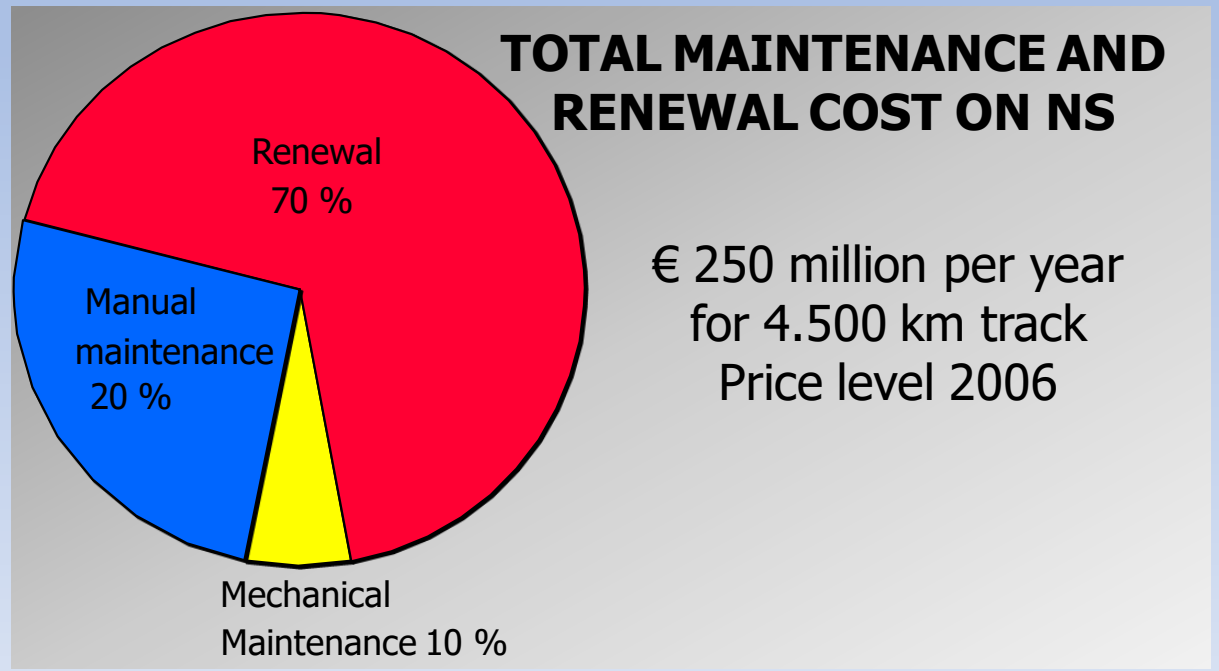
stasha.jovanovic@gmail.com

Why is weld quality so important?

Expected Cost Savings due to impact load reduction at welds:

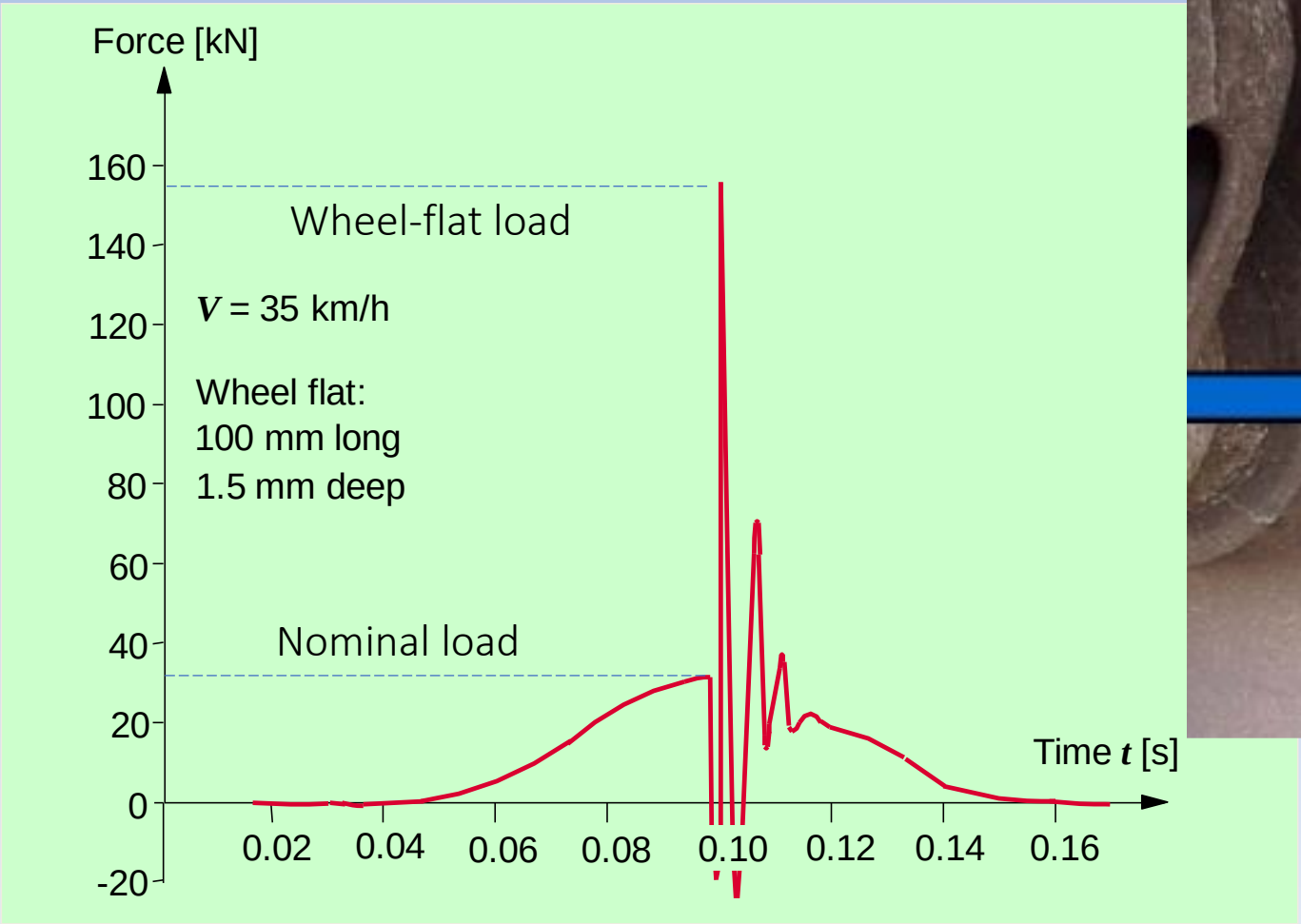
- 10 – 20 % of annual maintenance budget;
- ProRail budget in The Netherlands: ~ € 250 mio for 4,500 single track;
- Savings: € 25 – 50 mio total, or € 5 – 10,000 per km of single track every year.

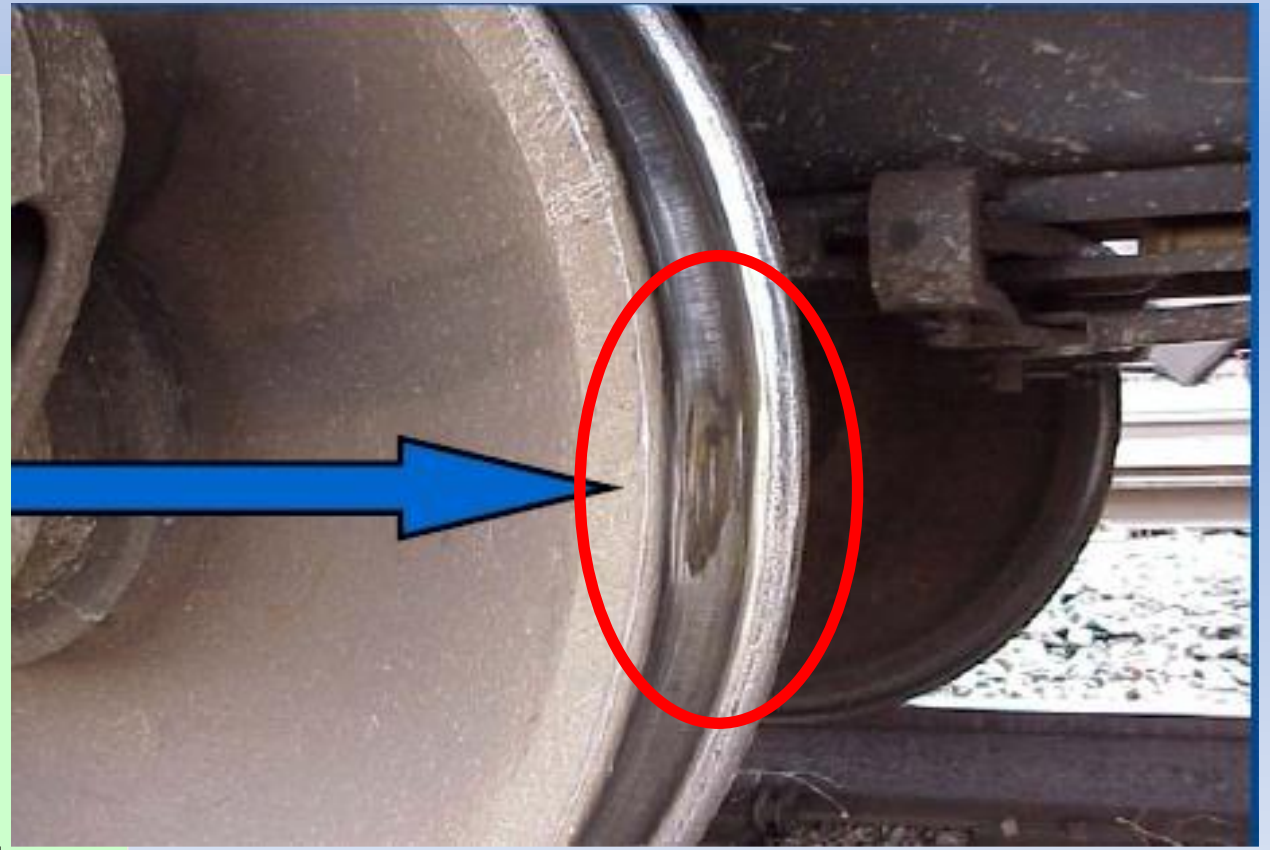
(Esveld)



stasha.jovanovic@gmail.com

Influence of wheel quality

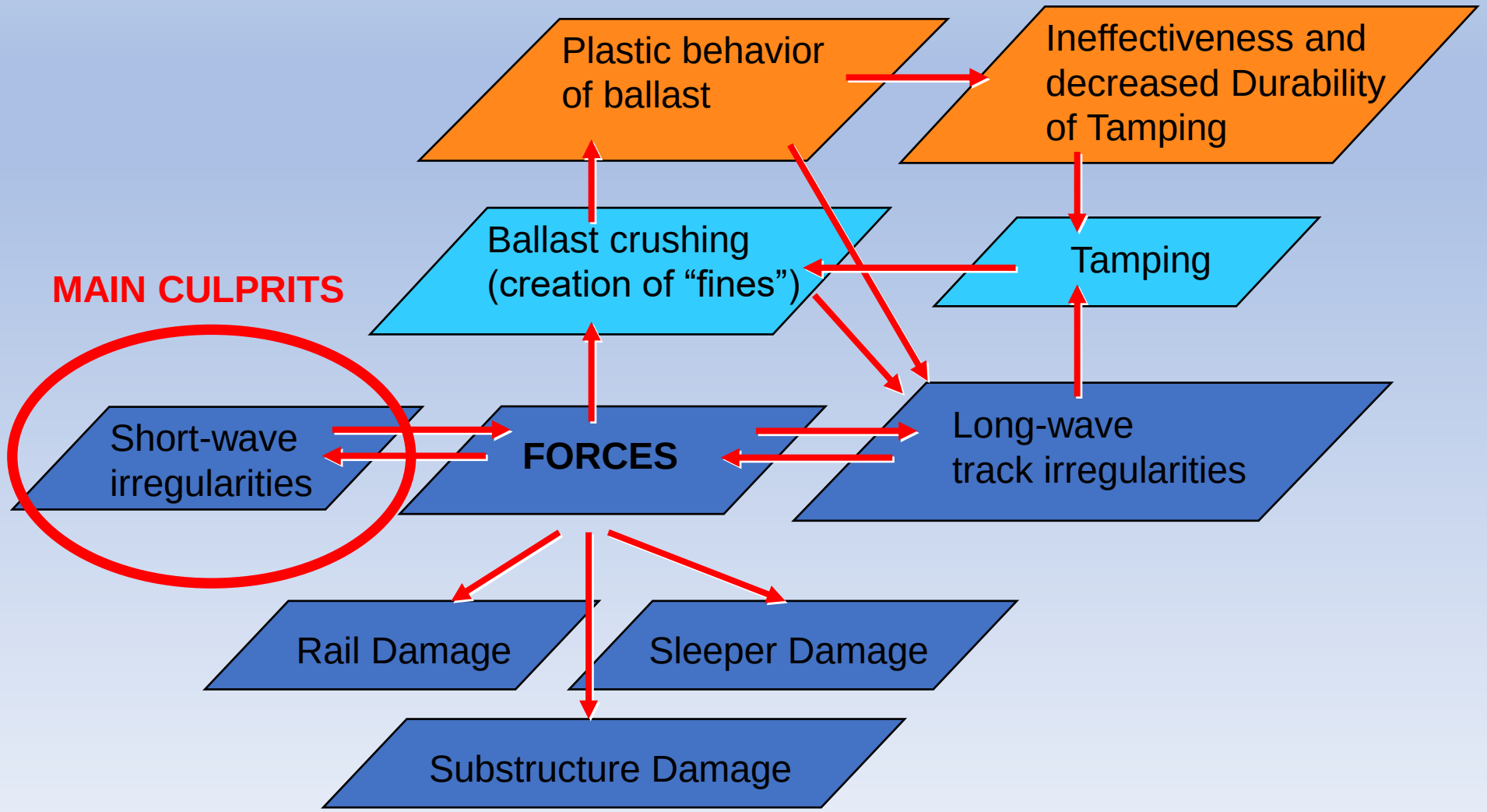




Impact of a wheel-flat on the force between rail and sleeper

stasha.jovanovic@gmail.com

Track Deterioration "Vicious Circle"



stasha.jovanovic@gmail.com

What can be done?

What to do:

- Measure track and rail geometry regularly
- Detect locations with faster-than-normal deterioration trend and repair them before the geometrical deviations cause high enough dynamic forces to cause permanent and costly damages

How to do it:

- Traditional Track Recording Vehicles (TRVs / “Measuring cars”)(?)
- Alternative measuring methods, especially **unattended measuring systems**, allowing virtually permanent coverage of the entire network

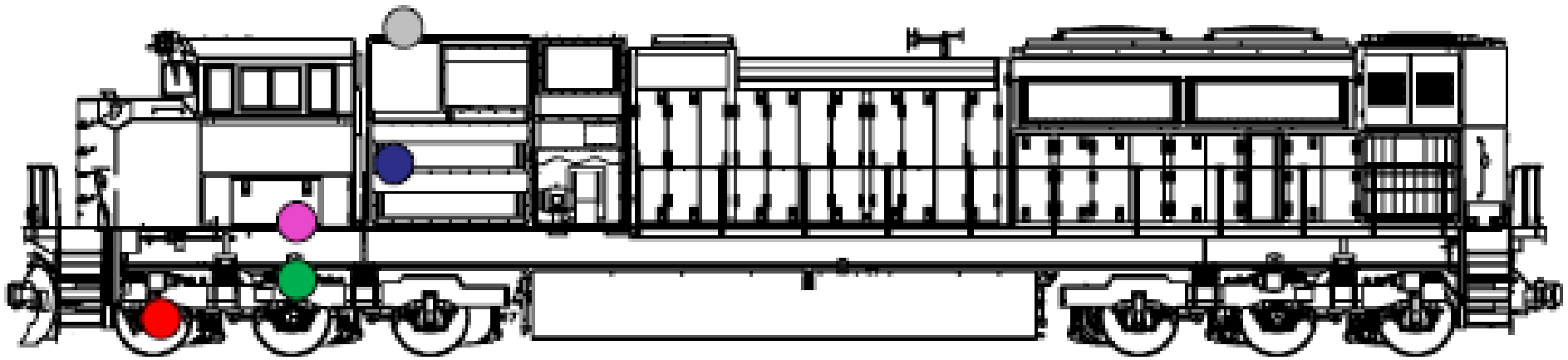
stasha.jovanovic@gmail.com

Typical TRV Operational Management

Total length of lines to survey	About 10.000 km
Survey Frequency	1 week / 3 months
Total amount of km covered in 1 year	80.000 Km
Average length surveyed in 1 working day	500 km
Acquired data in 1 month	1 Tb

stasha.jovanovic@gmail.com

V/TI (Vehicle/Track Interaction) Monitor Component Layout



- Antenna
- Main Unit
- Carbody Sensor
- Truck Sensor
- Axle Sensors

In North America alone, there are currently 435+ of V/TI Monitor systems, measuring 100,000 km daily and sending collected data to the central database.

stasha.jovanovic@gmail.com

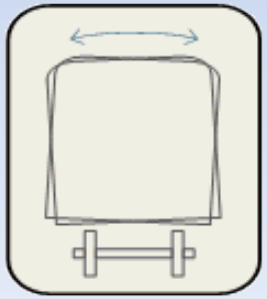
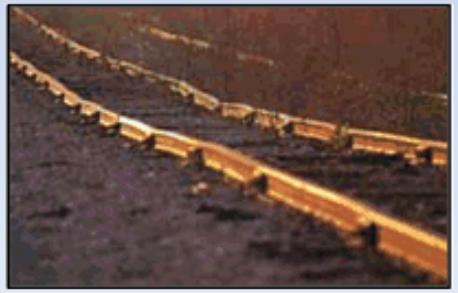
V/TI (Vehicle/Track Interaction) Monitor Component Layout

One channel of V/TIM system and one field in a database is reserved for each accelerometer, where everyone measures a specific exception type:

1. ***CarBody Vertical*** – CBV acceleration
2. ***CarBody Lateral*** – CBL acceleration
3. ***Truck Lateral*** – TRL acceleration
4. ***Axle vertical impact load*** – AXV1, AXV2 (axle acceleration individually measured for left and right side of axle box, which based on a specific real-time data processing algorithm and knowable axle loads and unspung masses, calculates the dynamic forces at wheel/rail contact)
5. ***Mid–chord Offset*** – MCO1, MCO2 ***track vertical geometry*** for both the left and right rail

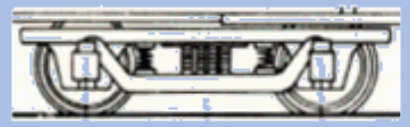
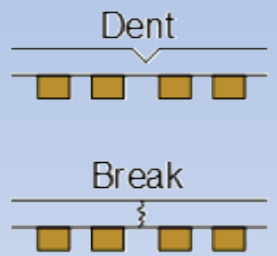
stasha.jovanovic@gmail.com

V/TI Monitor Exception Types Summary (1/2)

Exception Type	Look For:		Examples
CBV Carbody Vertical		• Look for repeated vertical profile dips in track • Look for mud and pumping conditions	
CBL Carbody Lateral		• Look for lateral alignment irregularity in track	
CBR Carbody Roll		• Look for staggered joints or repeated crosslevel irregularities • Only associated with coal car V/TI Monitors	

stasha.jovanovic@gmail.com

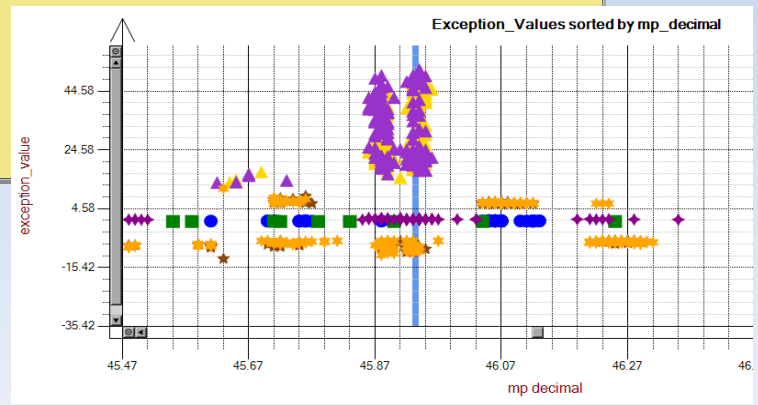
V/TI Monitor Exception Types Summary (2/2)

Exception Type	Look For:		Examples
TRL Truck Lateral		• Indicates truck hunting. • Look for worn wheel profiles, degraded dampers, worn gibs	
AXV1 and AXV2 Axle Vertical Impact		• Look for broken rail, broken joint, broken frog, battered joint, engine burn, crushed rail head, loose/missing bolts.	
MCO1 and MCO2 10-Foot Mid-Chord Offset Vertical Profile		• Look for mud and pumping conditions. • Look for pumping joints	

stasha.jovanovic@gmail.com

Visualization of data within VTI-TQI software

The segment postion within the observed track – total length of presented track ≈ 100 miles, ie. ≈160 km

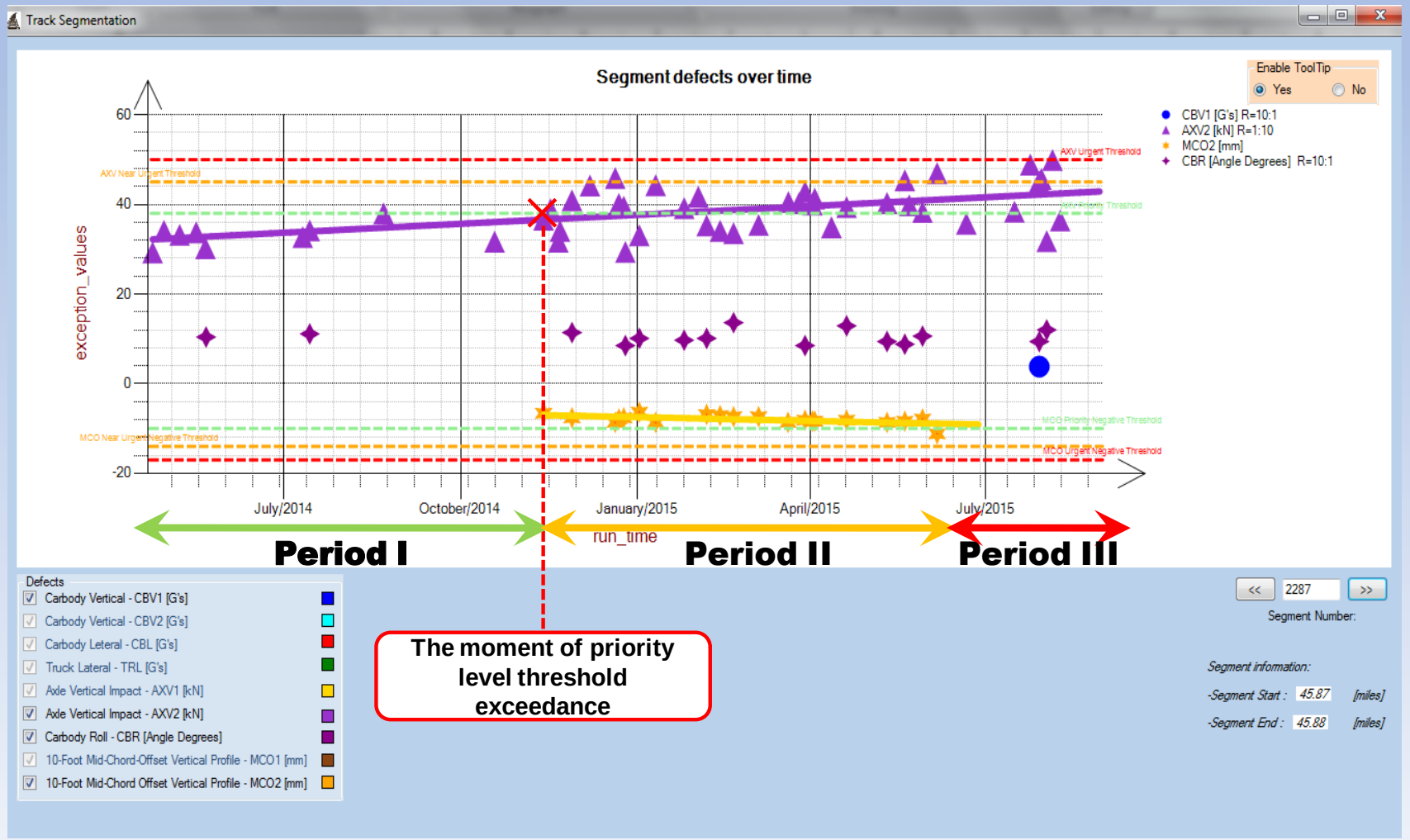


The zoomed view of segment within the observed track – total length of presented track ≈ 1 mile, ie. 1.60 km

"Segmet view" of defects sorted by time of their occurence - refers to segment length of 0.02 mile, ie.

stasha.jovanovic@gmail.com

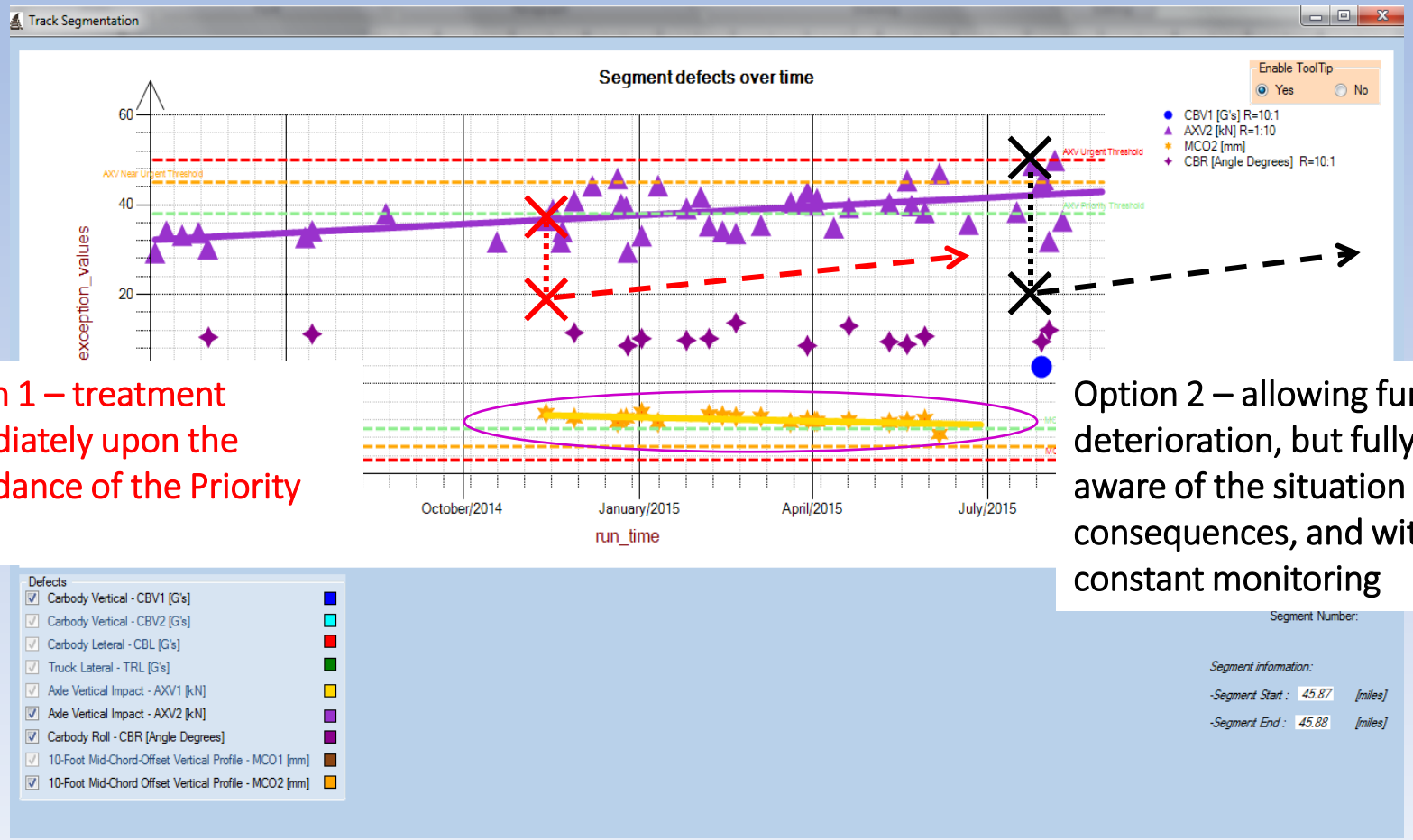
The influence of dynamic forces on track vertical geometry deterioration



The moment of priority level threshold exceedance

stasha.jovanovic@gmail.com

The influence of dynamic forces on track vertical geometry deterioration

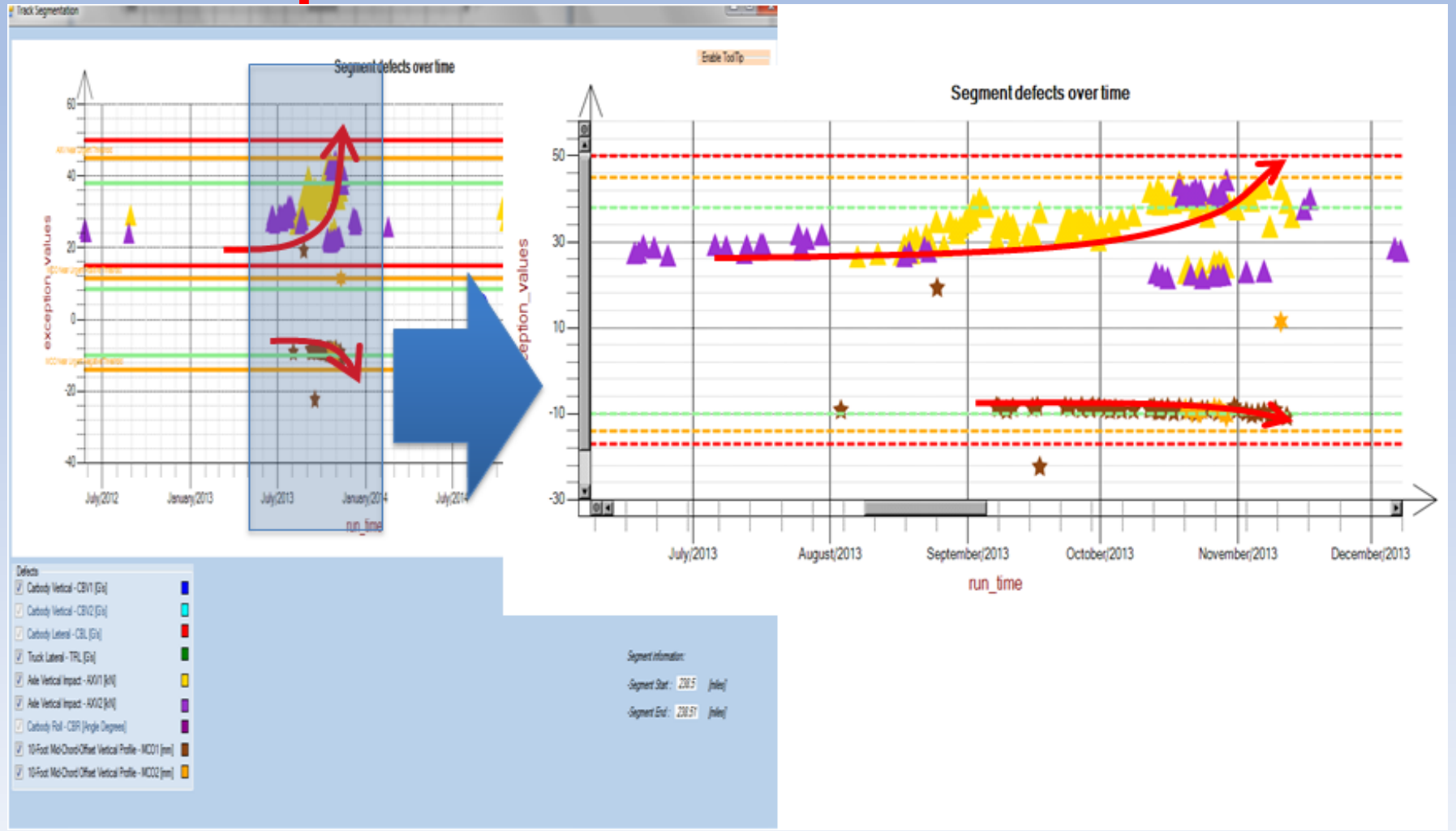


Option 1 – treatment immediately upon the exceedance of the Priority Limit

Option 2 – allowing further deterioration, but fully aware of the situation and consequences, and with constant monitoring

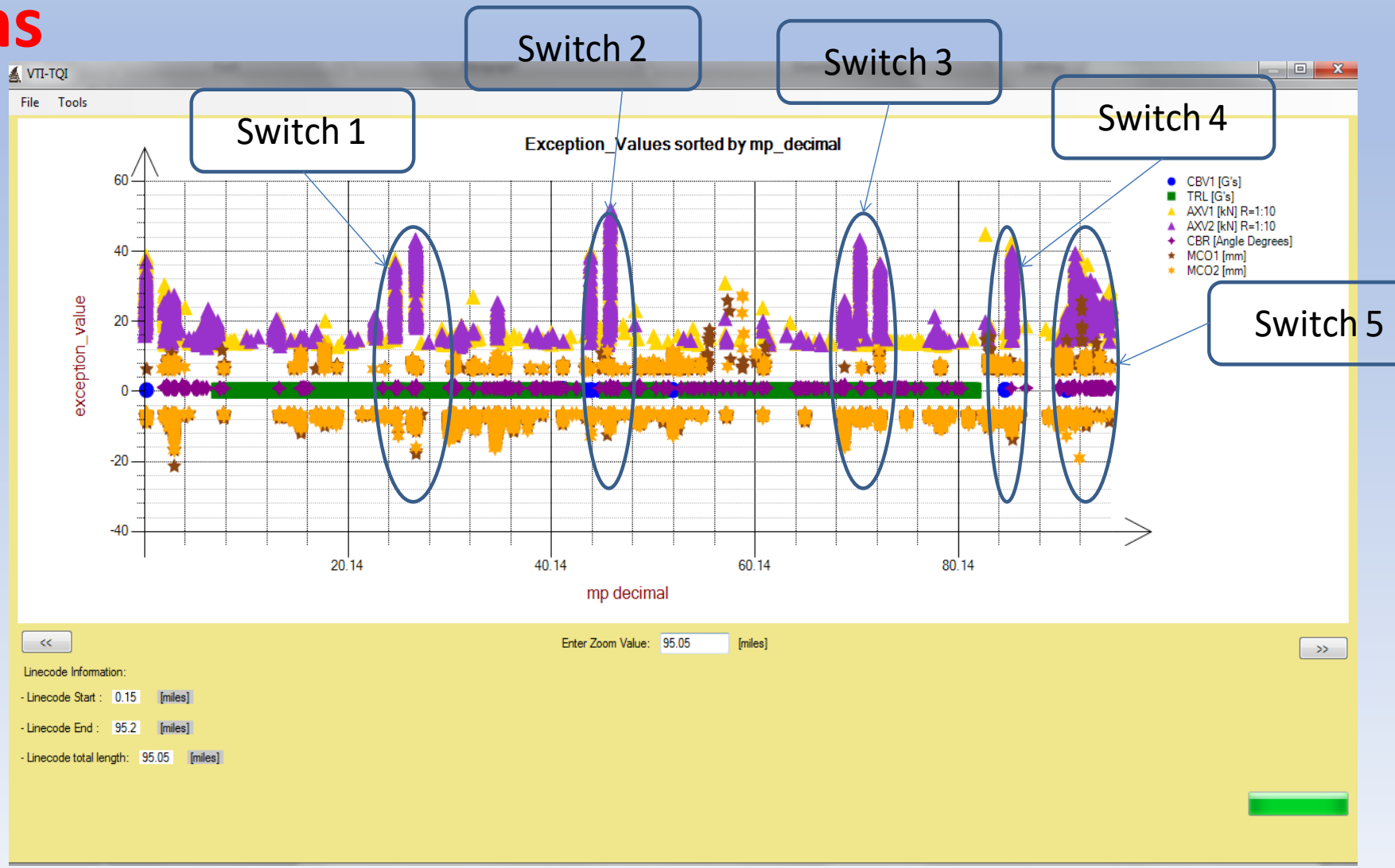
stasha.jovanovic@gmail.com

Extremely high growth of impact forces in a very short period of time of about 4 months



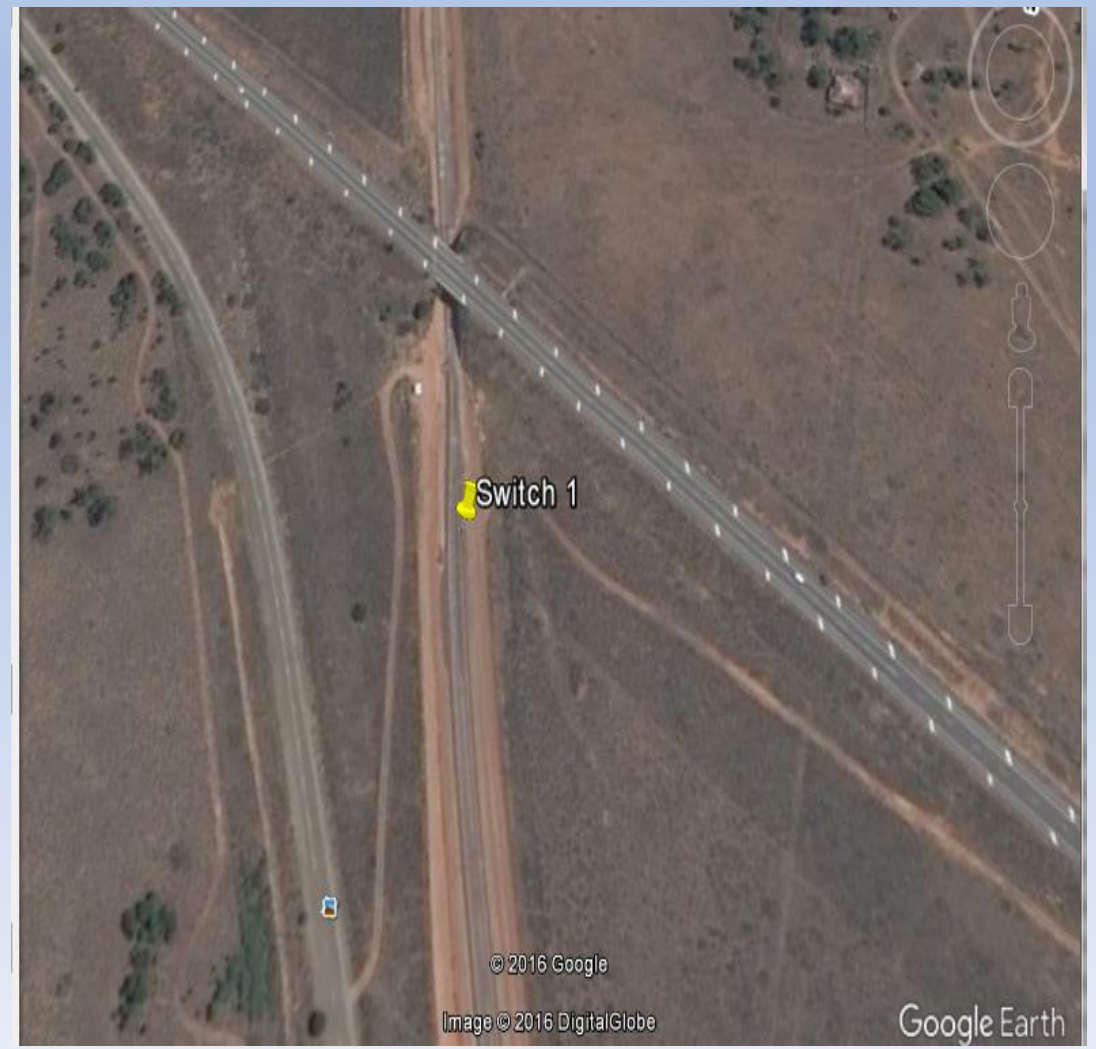
stasha.jovanovic@gmail.com

A characteristic situation from one of the investigated network regions



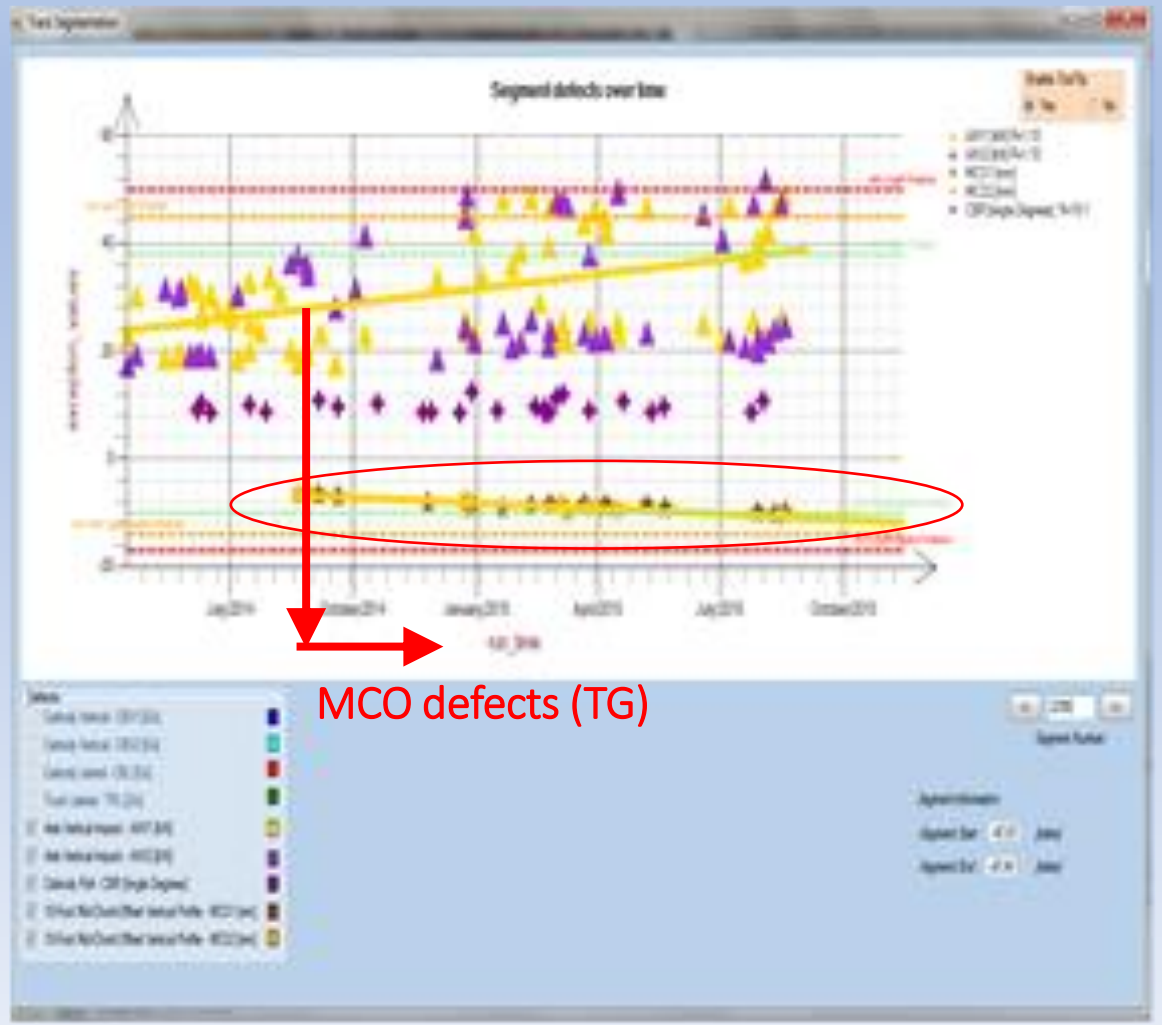
stasha.jovanovic@gmail.com

Switch 1 - Segment view



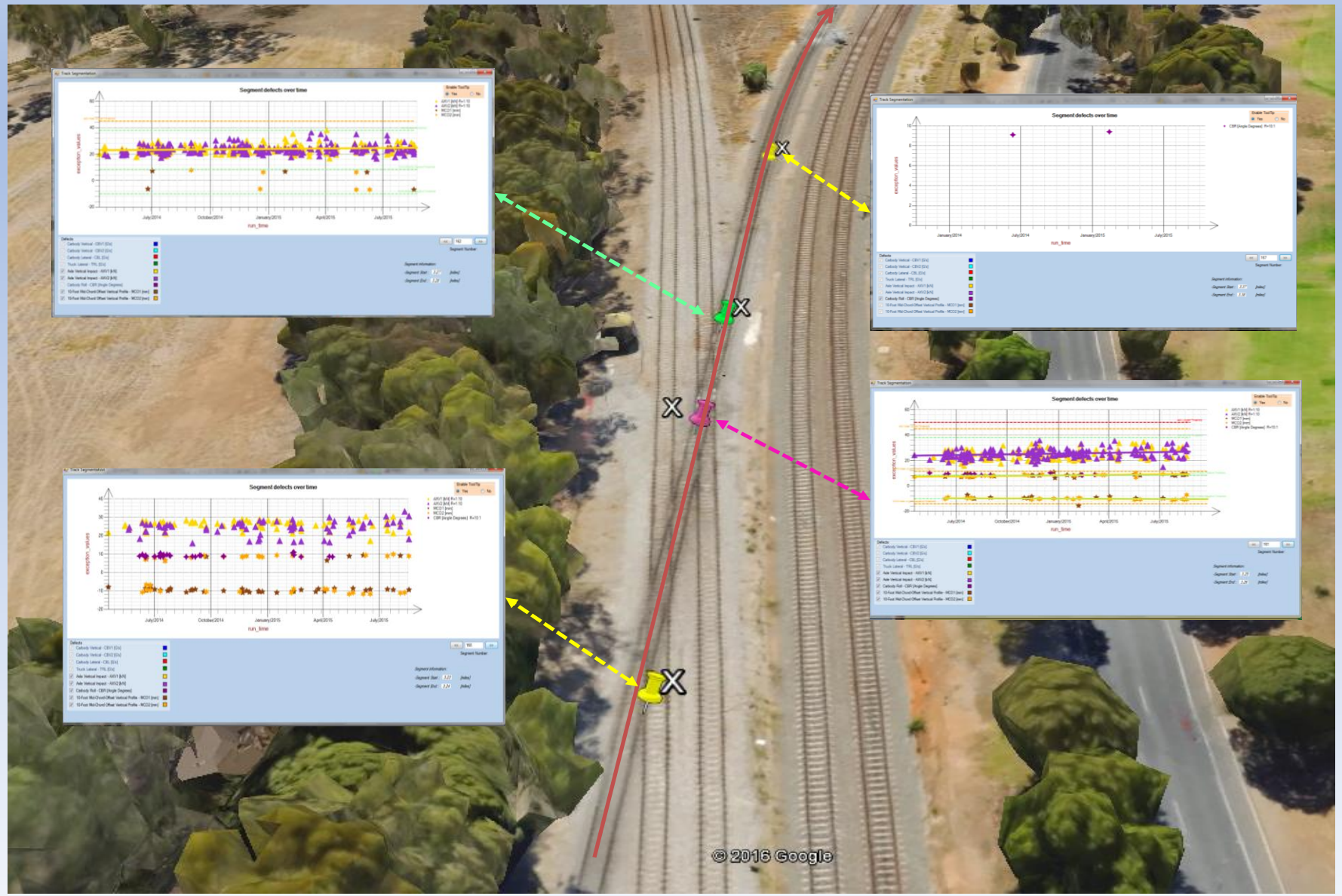
stasha.jovanovic@gmail.com

Switch 2 - Segment view



stasha.jovanovic@gmail.com

Defects generated at two consecutive crossings



stasha.jovanovic@gmail.com

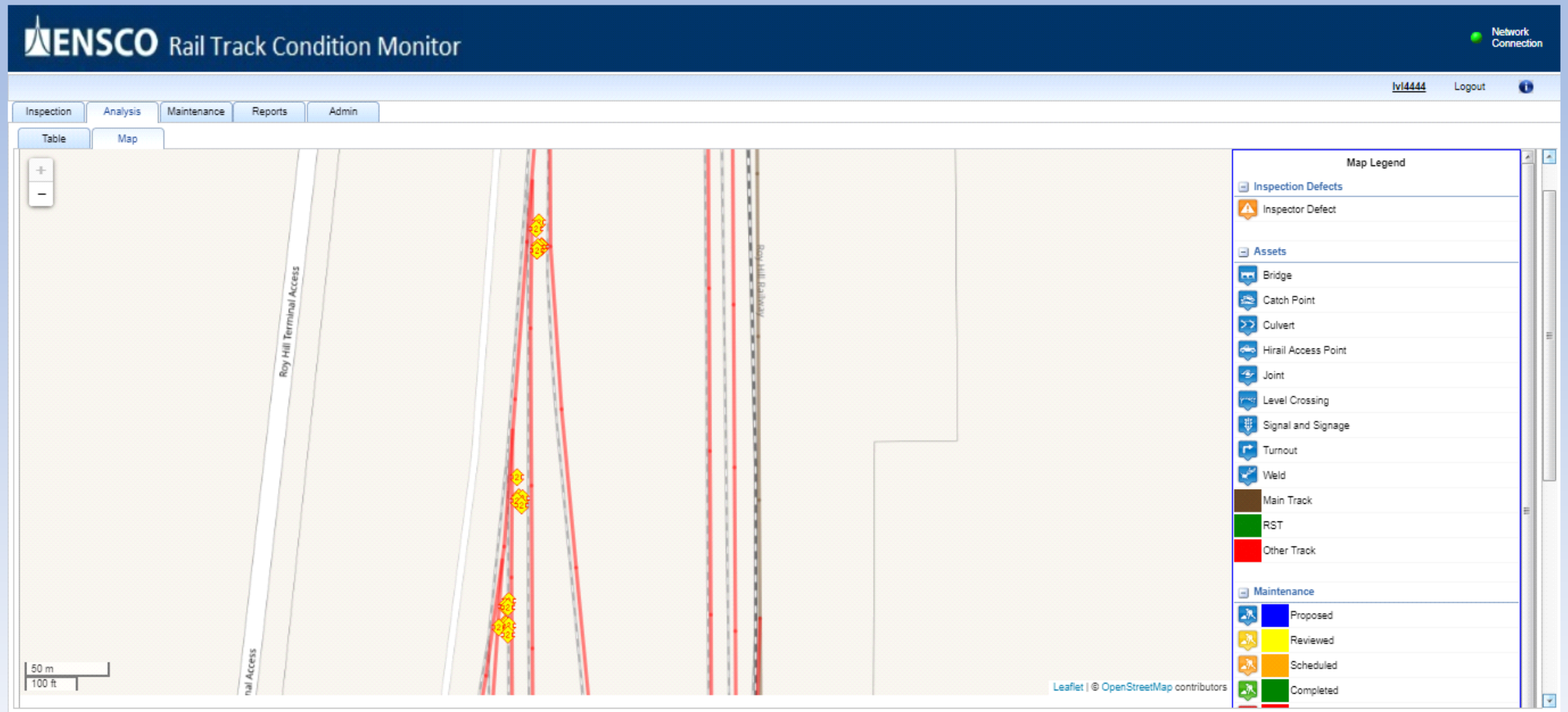
How to use V/TI Monitor data

AMA – Automated Maintenance Advisor

stasha.jovanovic@gmail.com

How to use V/TI Monitor data

AMA – Automated Maintenance Advisor

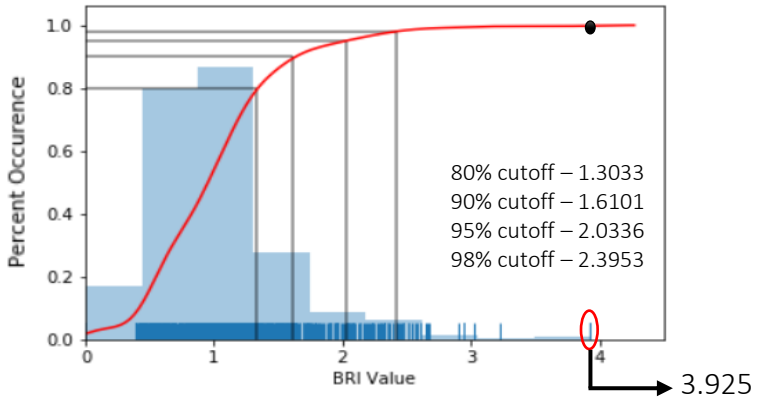


stasha.jovanovic@gmail.com

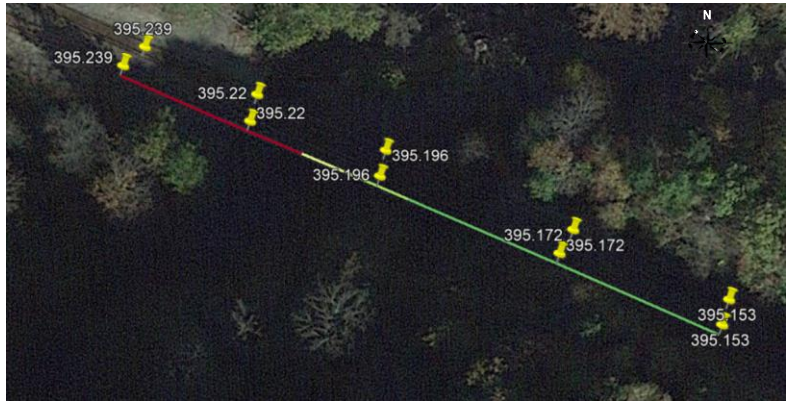
How to use V/TI Monitor data

AMA – Use of VTI data for Bridges Risk Index (BRI)

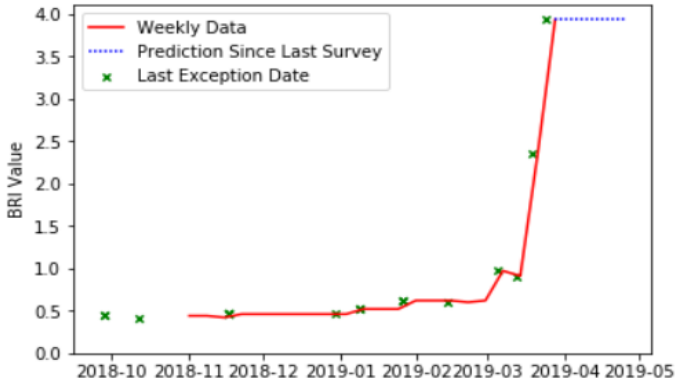
6 Month Cumulative Distribution



Map View



Historic Performance

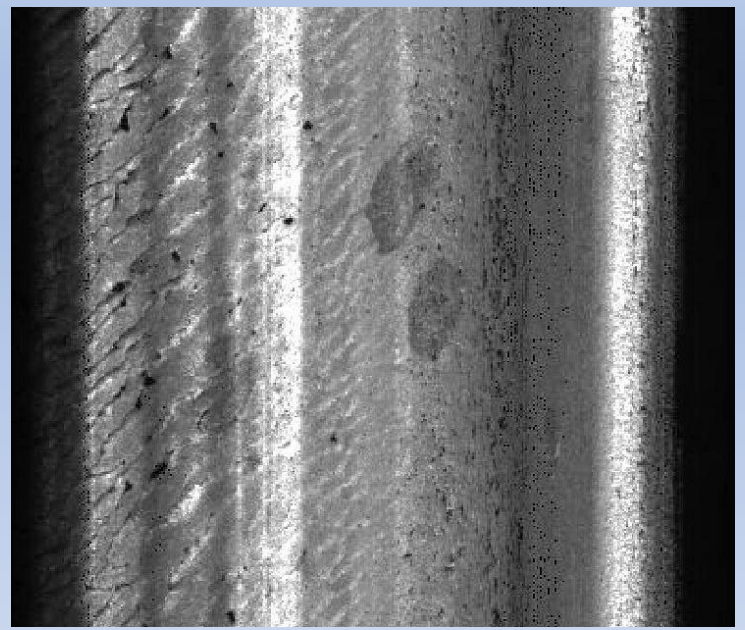


Remarks and Considerations

- BRI – 3.93
- Risk is observed at bridge approach
- Last Exception Date: 3/25/2019
- Report Date: 4/25/2019
- Sudden risk increase identified on 3/19/2019
- Primary Influence: MCO

stasha.jovanovic@gmail.com

Machine Vision and Strip Chart Assessment of Rolling Contact Fatigue



- Machine Vision technology is growing in the rail industry.
- Line Scan Cameras are used to capture high resolution images of surfaces, such as the rail surface.
- **Traditionally machine vision algorithms look for distinct defects.**
- These defects are reported individually and are intended to be repaired individually.
- In the case of rail surface, this process works well for detecting broken rail, engine burns, etc…
- **However, to use this approach for RCF and other surface damage quantification, it creates data overload.**

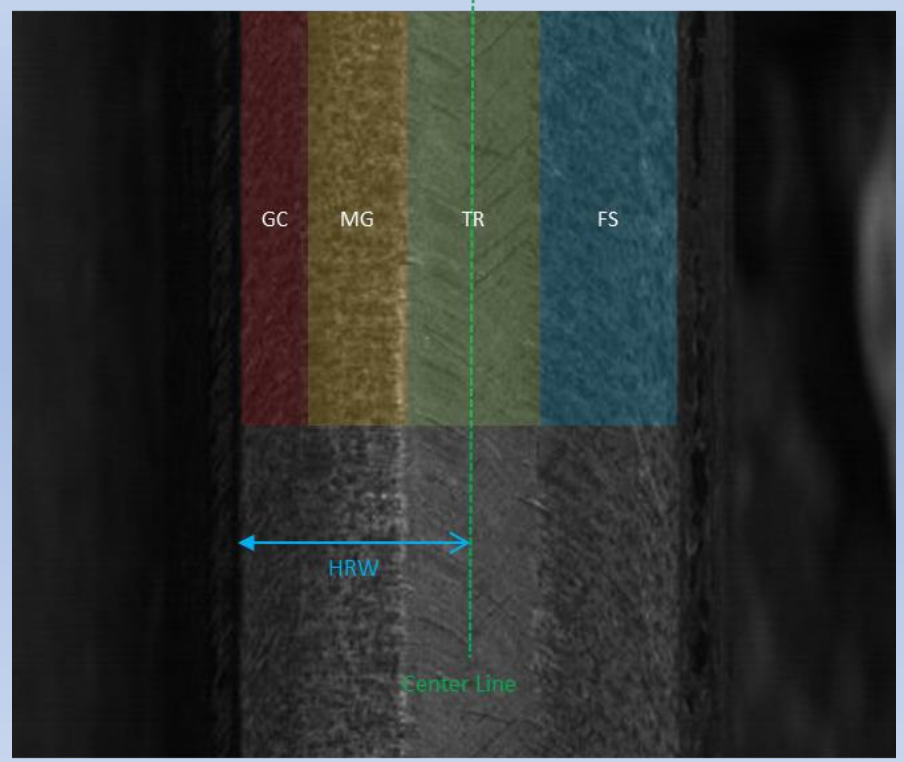
stasha.jovanovic@gmail.com

Step 1: Grinding Detection

- Heavy grinding marks are important to identify so that they don't interfere with the machine vision calculations.
- An algorithm was developed to determine if the rail surface has been ground or not ground.
- If the surface was determined to be ground, the band segment calculations are adjusted.

Step 2: Rail Surface Bands

- Rail head is split into four bands.
- Band width is adjustable
- Each band is 1-foot (250mm) in length
- A fifth band is included of the full rail width
- 5 rail surface bands total.



Each band 1-foot segment has the following values calculated:

- Four machine vision calculations:
  - Crack Density
  - Ave Crack Width
  - Ave Crack Angle
  - Surface Damage Area
- A fifth channel is a calculated index that weights the above items into one channel.
- 5 calculated values per band segment.

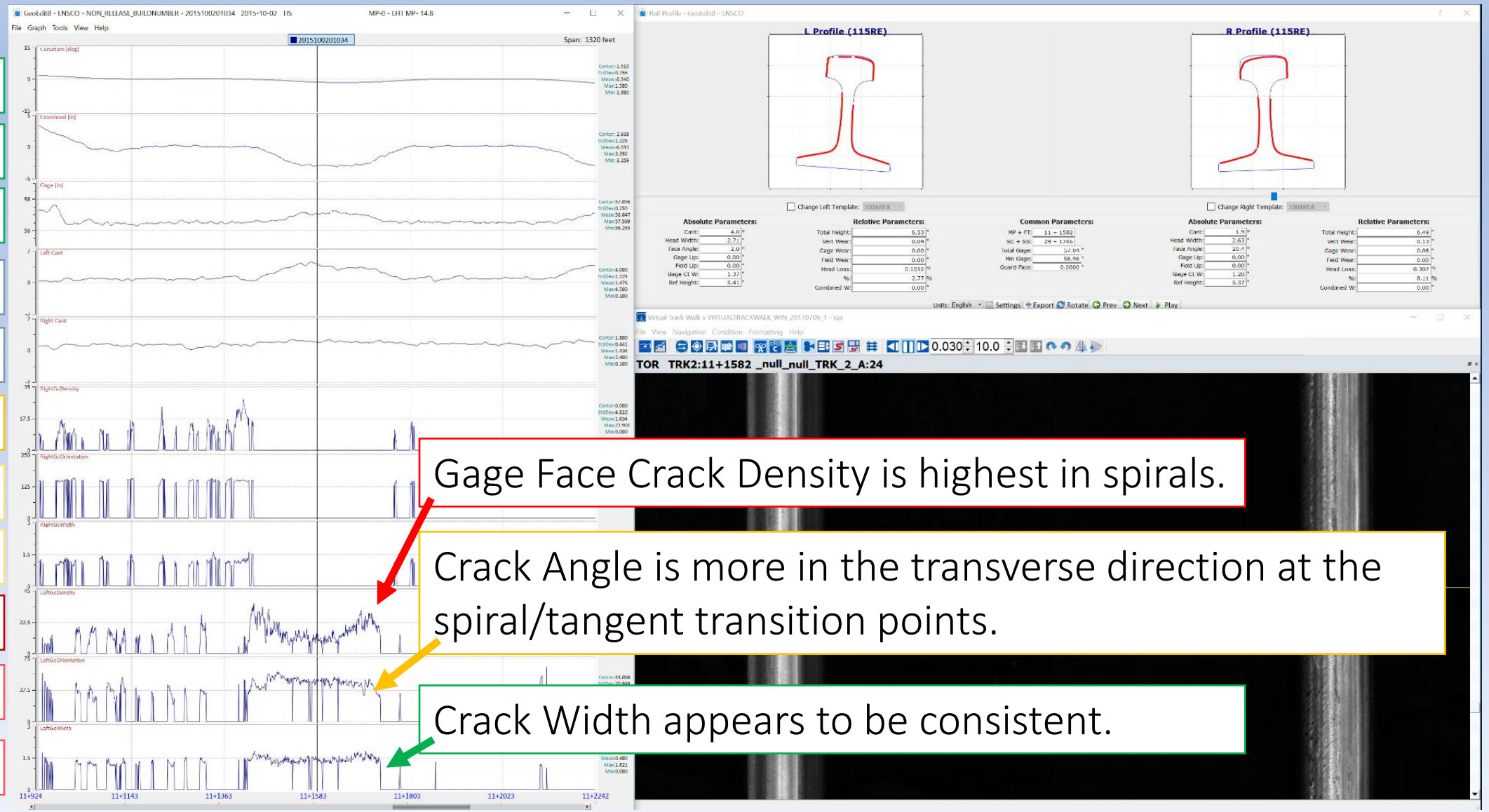
Summary:

- 5 rail surface bands per rail.
- 5 calculated values per band.
- 2 rails
- ***5x5x2 = 50 strip chart channels***

stasha.jovanovic@gmail.com

Step 3: Analysis

- Curvature (deg)
- Crosslevel (in)
- Gage (in)
- L Cant (deg)
- R Cant (deg)
- L GF Crack Density
- L GF Crack Angle
- L GF Crack Width
- R GF Crack Density
- R GF Crack Angle
- R GF Crack Width



Gage Face Crack Density is highest in spirals.

Crack Angle is more in the transverse direction at the spiral/tangent transition points.

Crack Width appears to be consistent.

stasha.jovanovic@gmail.com

Autonomous vehicle-track interaction monitoring and railway infrastructure maintenance

Thank you for your kind attention !

Prof. **Stasha Jovanovic**, Ph.D.
Ensco Inc., Springfield, USA & Faculty of Technical Sciences, Novi Sad, Serbia

Predrag Tešić, M.Sc. Civ. Eng., Tangram projekt d.o.o., Novi Sad, Serbia

Matthew Dick, Ensco Inc., Springfield, USA

stasha.jovanovic@gmail.com