
# A Novel Fiber Optic Sensing System for Weighing in Motion (WIM) and Wheel Impact Load Detection (WILD)

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3 Ente Autonomo Voltruno

4 Rete Ferroviaria Italiana

5 Ansaldo STS

# The "Sicurfer" Project

Sicurfer
Tecnologie per la Sicurezza Ferroviaria

UNIONE EUROPEA
Fondo europeo di sviluppo regionale

PON Ricerca e Competitività 2007-2013

Ministero dell'Istruzione, dell'Università e della Ricerca

Ministero dello Sviluppo Economico

investiamo nel vostro futuro

*PON Ricerca: 2012-2015*

*Innovative Technologies for Safety and Security of Railway Systems*

*Main Partners*

Ansaldo STS
A Hitachi Group Company

ISARail
Independent Safety Assessor

Università degli Studi del Sannio

RFI
RETE FERROVIARIA ITALIANA
GRUPPO FERROVIE DELLO STATO ITALIANE

CIRCUMVESUVIANA

Contact Srl

SELEX ELSAG
Secure Networking Solutions
A Finmeccanica Company

softeco sismat
information technology

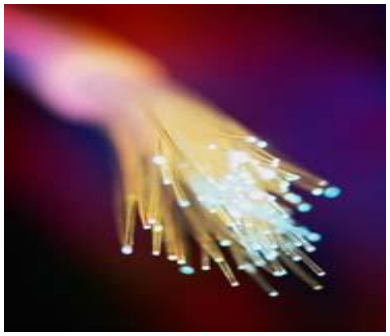
STRAGO

intecs
the Brainware company

3F & EDIN

# Objective

One of the Main Objective of the Sicurfer Project was the development of a **Novel and Smart monitoring system** entirely based on optical fiber technology and fiber optic sensors, able to perform **weighing in motion (WIM)** as well as **wheel impact load detection (WILD)** in railways assets.



A Multidisciplinary Team was selected to cover the different aspects of the research activities involved in

Ansaldo STS
A Hitachi Group Company

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optoXsmart
OPTOELECTRONIC AND SMART SYSTEMS

RFI
RETE FERROVIARIA ITALIANA
GRUPPO FERROVIE DELLO STATO

OPTOELECTRONICS group
University of Sannio

E.A.V.

# WIM – WILD System
# Dual Functionalities in one System

## WEIGHING IN MOTION


Early warning for overloads and imbalances

✓Reduce tracks damaging
✓Reduce on board failures
✓Improve Security Levels



## DEFECTED WHEEL IDENTIFICATION


Early Warning of Defected Wheels

✓Towards on condition maintenance
✓ Improved Safety levels
✓Reduction of infrastructure damaging



# Commercial WIM & WILD Systems

## *Load cells*

- Invasive Installation (Instrumented sleepers)
- Electrical connections near the rails

| Muiltirail Shenck SYSTEM | |
|---|---|
| **Technology** | Load cells |
| **Installation** | instrumented sleepers |
| **WILD measurements** | wheelflats |
| **Accuracy WIM** | 2% wagon weight (at 10- 60 km/h) |
| **Temperature** | -30°C a 70°C |
| **Speed** | 10 - 250 km/h (30-80km/h for WILD) |

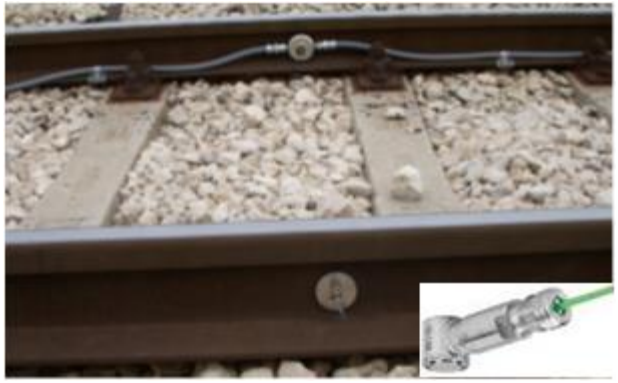
## *Strain gauges*

- Electrical connections near the rails
- Reduced multiplexing capability

| WIMWIM SYSTEM | |
|---|---|
| **Technology** | Electrical Strain gauge |
| **Installation** | Metallic structure near the rail |
| **WILD measurements** | Short wheelflats |
| **Accuracy WIM** | 2 % |
| **Temperature** | -30°C a 70°C |
| **Speed** | Not indicated |

## *Quartz sensors*

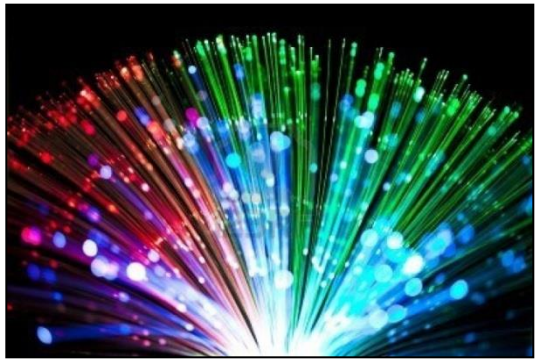
- Invasive Installation (drilling of the rails)
- Needs electrical connections



| Kistler SYSTEM | |
|---|---|
| **Technology** | Quartz sensors |
| **Installation** | drilling of the rail |
| **WILD measurements** | Wheelflats |
| **Accuracy WIM** | 2 % |
| **Temperature** | – 30°C a 80 °C |
| **Speed** | 5-350 km/h (not defined for WILD) |

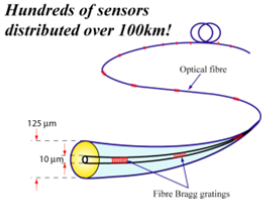
# Enabling Technology

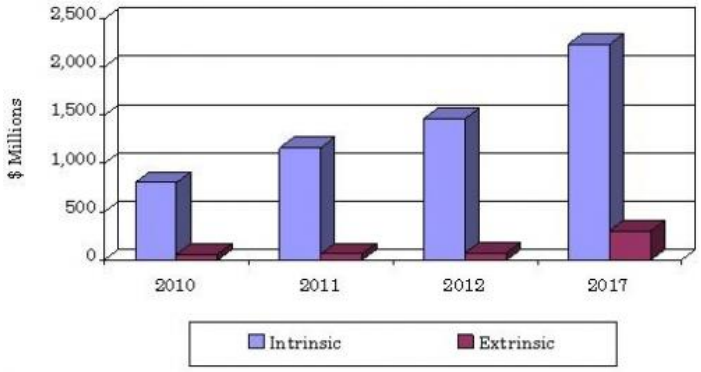
# Optical fiber Sensors: All-Around Platforms for Intelligent Sensing



An attractive sensing solution for Industrial Applications:

- *Linear Output*
- *Small and Lightweight*
- *WDM & TDM Multiplexing*
- *Mass Producible*
- *Reflective & Transmission Operation*
- *Single & Multi Point Sensing*
- *Multi Parameter Sensing*
- *Long Range*
- *Reasonable Cost*
- *Durable*




## Applications: Segment Areas

**Oil & Gas**
- Reservoir monitoring
- Downhole P/T sensing
- Seismic arrays

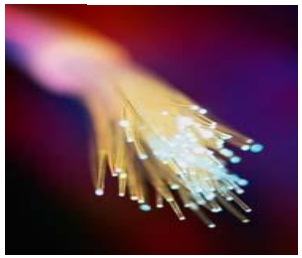
**Energy Industry**
- Power plants
- Boilers & Steam turbines
- Power cables
- Turbines
- Refineries

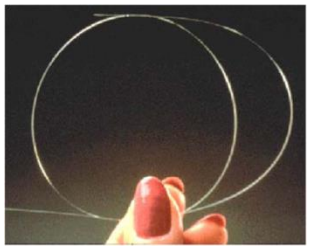
**Aerospace**
- Jet engines
- Rocket & propulsion systems
- Fuselages

**Underwater**
- Leaks in subsea pipeline monitoring
- Flood detection
- Hydrophone

**Civil**
- Bridges
- Dams
- Road
- Tunnels
- Land slides

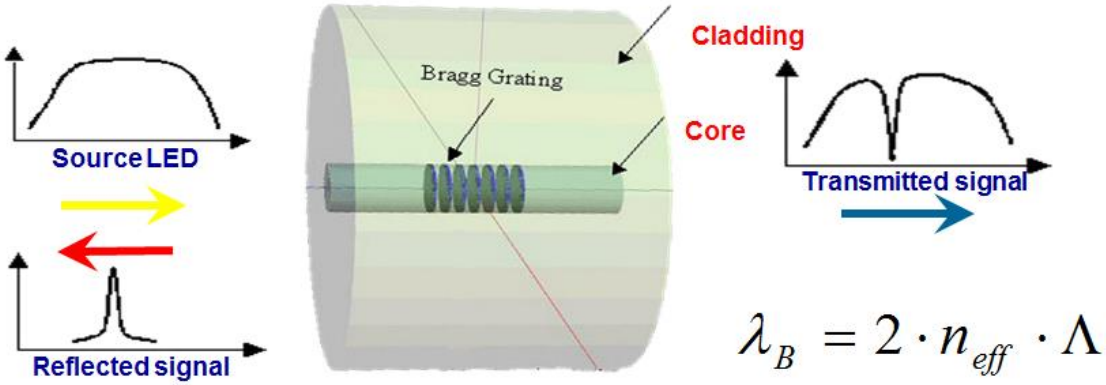
**Transportation**
- Rail monitoring
- Weight in motion
- Carriage safety





# Fiber Bragg Gratings as Sensing Element

**An In fiber component completely integrated in the core of standard optical fibers able to select in reflection only a single frequency component of the input light**



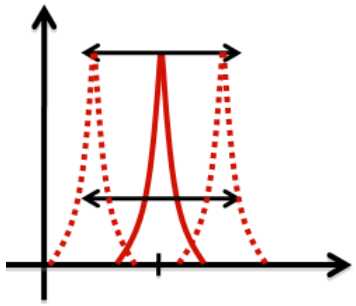

$$\lambda_B = 2 \cdot n_{eff} \cdot \Lambda$$

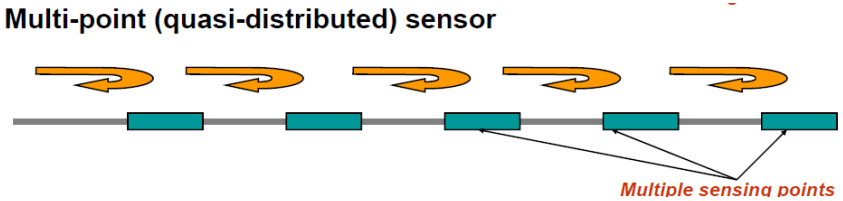
**An optical filter for frequencies manipulation within standard optical fibers used for TLC**

**But…also an extremely intriguing platform for sensing**

✓**Temperature Sensor**

✓**Static and Dynamic Strain Sensor**

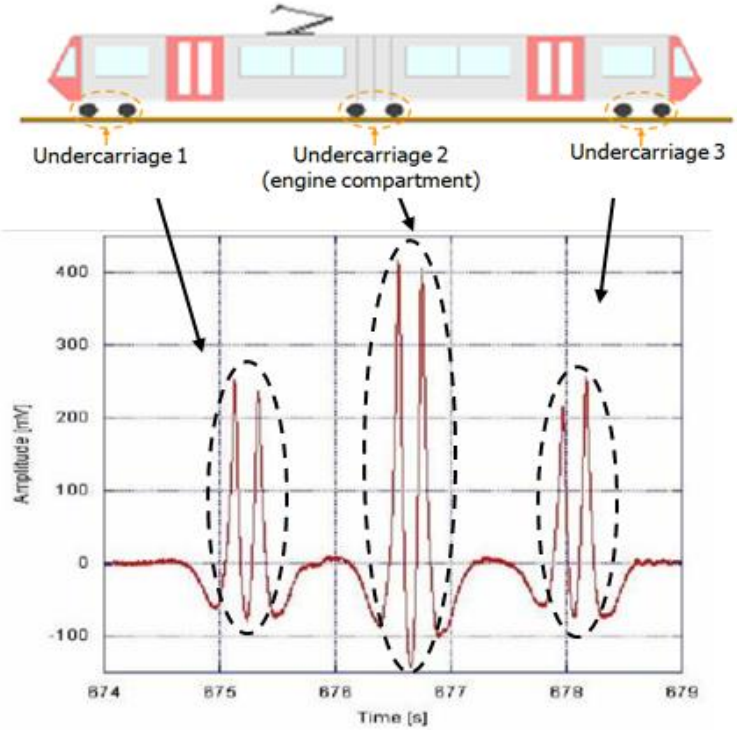





## Main Features

- Distributed and Multiparameter Capability
- Standardised TLC Platforms
- Fully Passive (no electrical connections in the measuring zone)
- Immune to electromagnetic interference
- Mass Produced
- High Resolution (0.1°C, 1με)

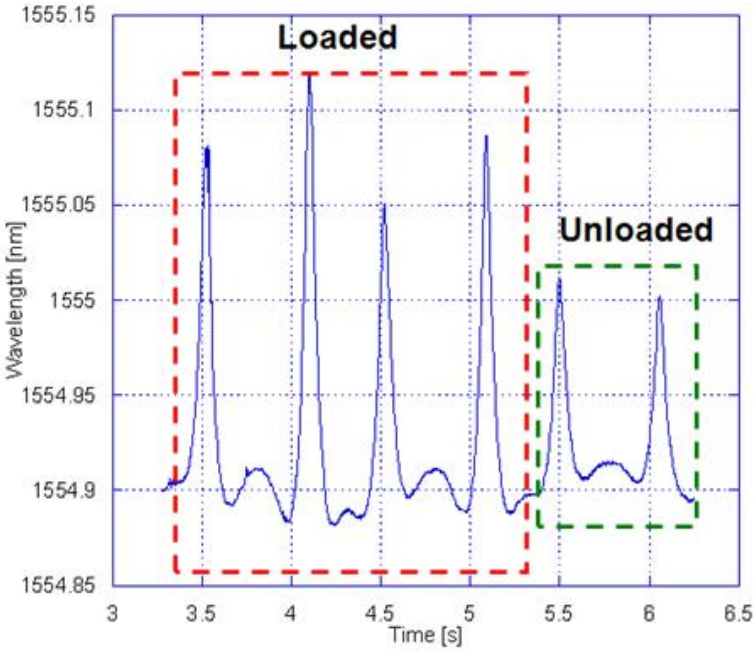
# Principle of operation




***A Single FBG element fixed to the rail tracks provides an output signal in the time domain composed by several peaks***

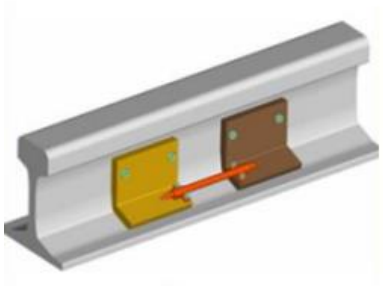
***Each peak is related to a single wheel passing over the sensing region***

***The amplitude of each peak retrieves information about the weight of the associated train wheel***

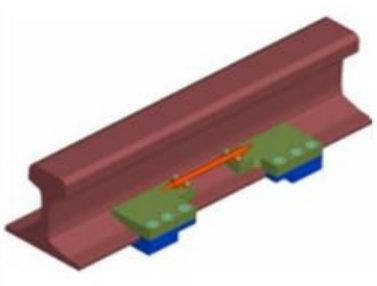


# The Sensor Kit

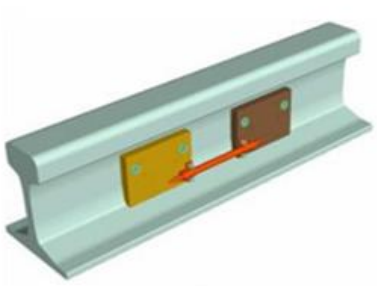
Anchor solution A



Anchor solution B

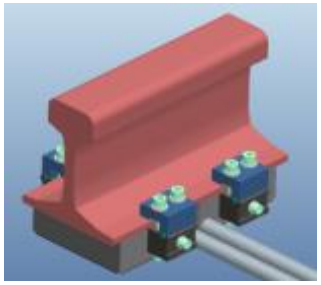


Anchor solution C

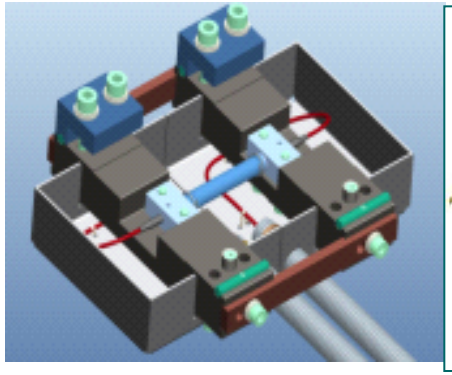


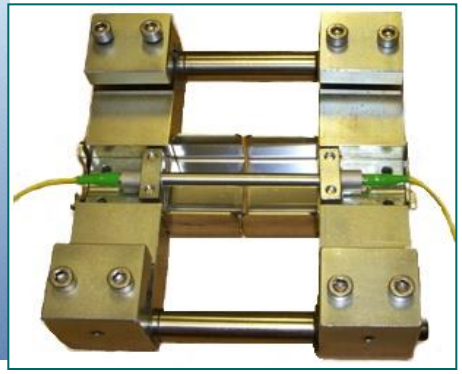
## FIRST TRIALS: TOWARDS AN ENGINEERED SOLUTION

## THE OPTIMISED SENSOR KIT



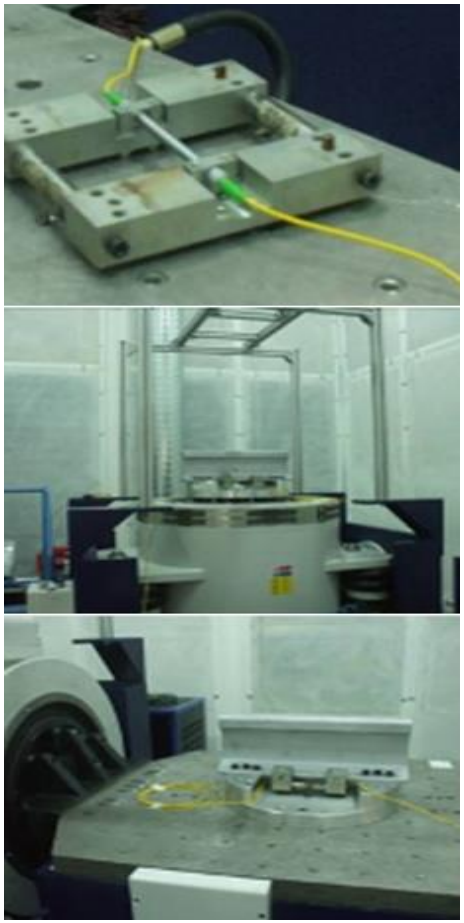
- Noninvasive
- No drilling of the rail
- Reduced installation time
- Easily removable





# Kit Certification

## Mechanical tests



- Vibrations: up to 280 $m/s^2$
- Shock: 2500 $m/s^2$/1ms

## Solar irradiation tests

Maximum level of solar radiation :
1120 W/m2. Temperature:60°C

## Climatic tests

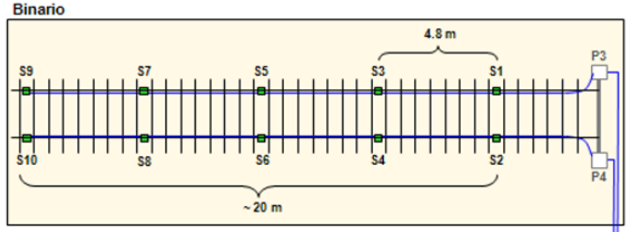
- Temperature changes : -40°C ÷ +85°C
- Hot dry test: 70°C, U.R. ≤ 60%
- Hot wet test: 55°C, U.R. 95%
- Cold test: -25°C

## Immersion tests in sand and water

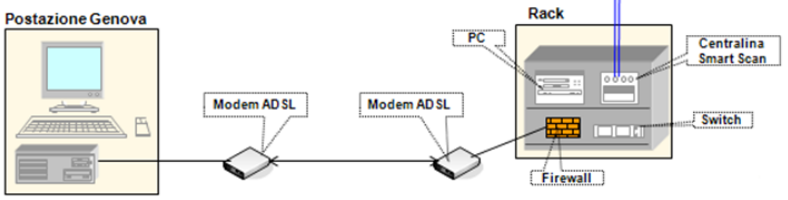
300 liters of water ( h 50 cm) – 75 kg of sand (h 30 cm)

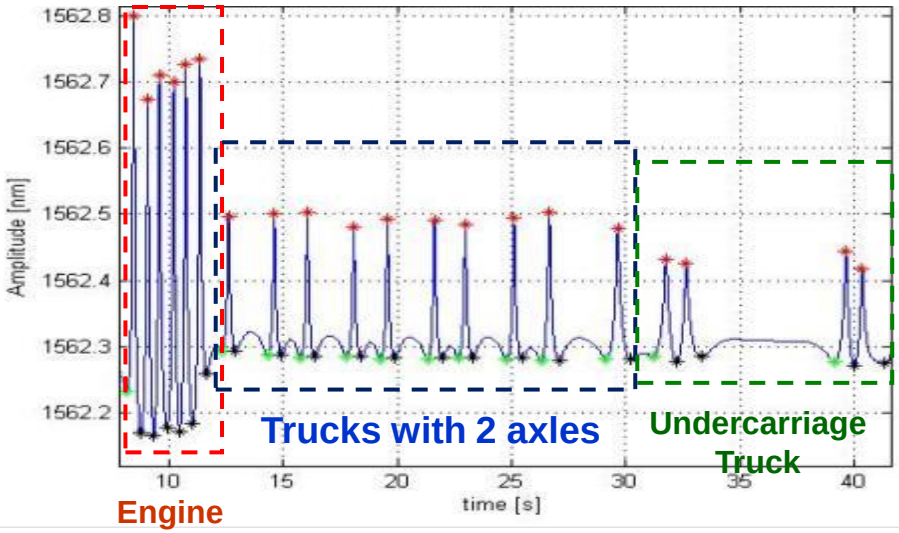
✓ **In compliance with the standards EN50125-3 and IS402** (conducted in ACCREDIA laboratories)

# WIM Functionality: Preliminary Validation Tests




- Sensors Number: 10
- Sensorised Section length: 20m
- Fiber optic cabling ensures total electrical insulation

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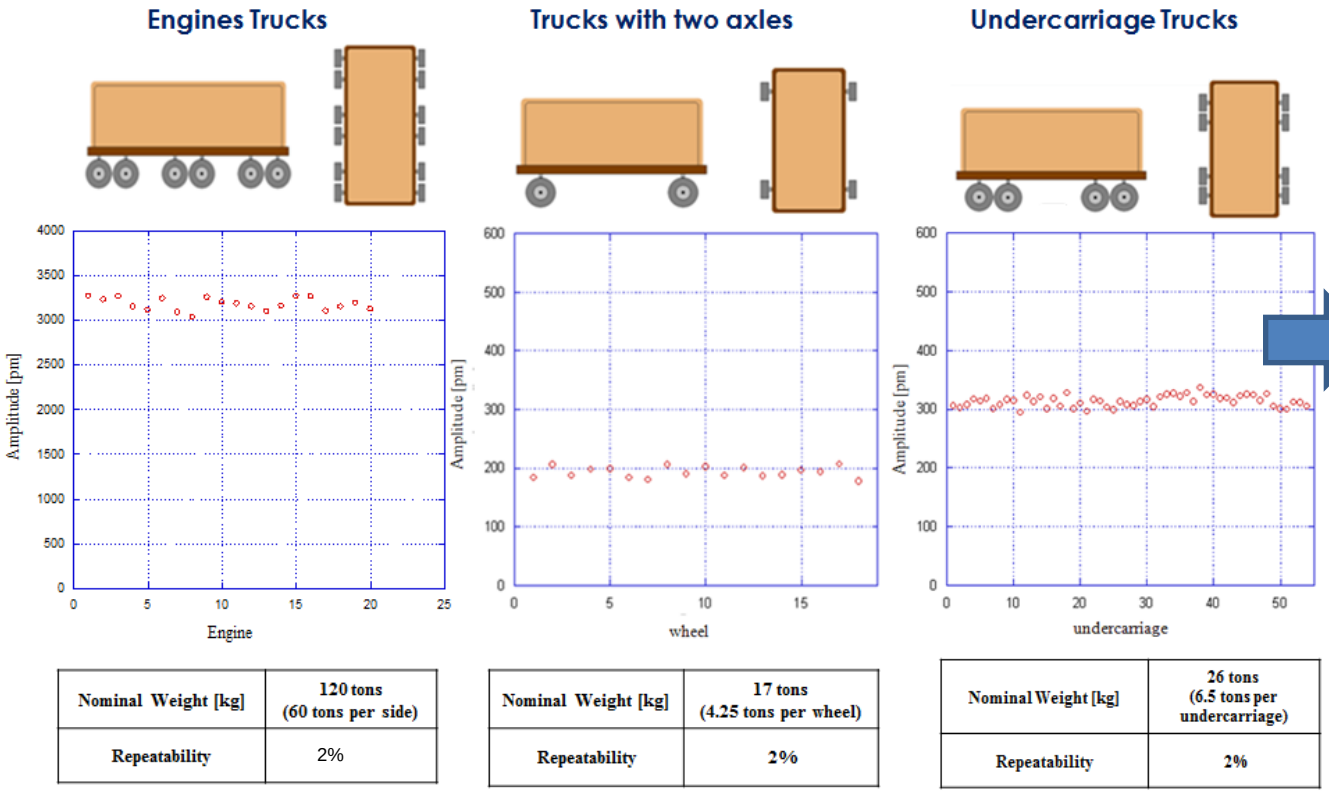
GRUPPO FERROVIE DELLO STATO

## Marcianise – Maddaloni Site

# WIM functionality: preliminary validation tests

## Repeatability Tests

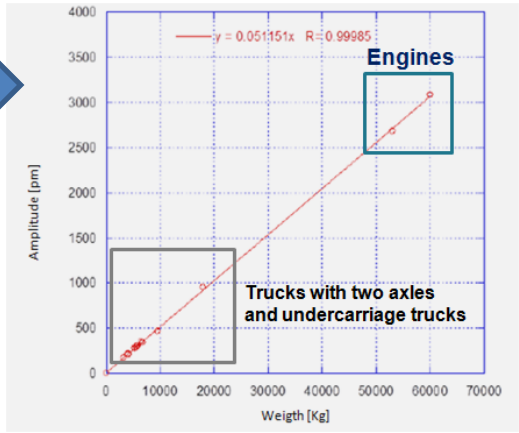



| Nominal Weight [kg] | 120 tons (60 tons per side) |
|---|---|
| Repeatability | 2% |

| Nominal Weight [kg] | 17 tons (4.25 tons per wheel) |
|---|---|
| Repeatability | 2% |

| Nominal Weight [kg] | 26 tons (6.5 tons per undercarriage) |
|---|---|
| Repeatability | 2% |

## Linearity Tests




- **Fast and Reliable Calibration** using exclusively locomotives, no need for ad hoc calibration trains
- In line **Auto-calibration and Re-calibration without interrupting the infrastructure operation**

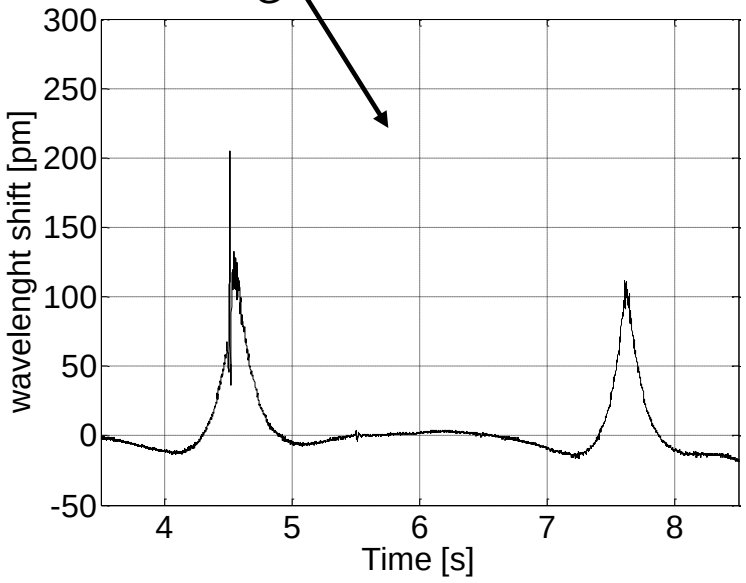
| Tested 22 trains | WIM Accuracy % | |
|---|---|---|
| Tested systems | Optical WIM System | Commercial System |
| Engine Truck | 2 | 8 |
| Undercarriages Truck | 2 | 4 |
| Truck with 2 axles | 2 | 7 |

# Adding WILD Functionalities

**If we separate the static and dynamic component of the sensor response**

FB

G

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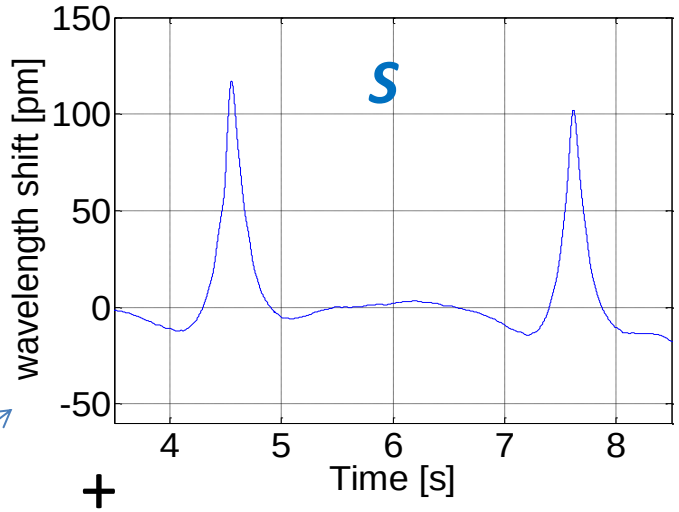
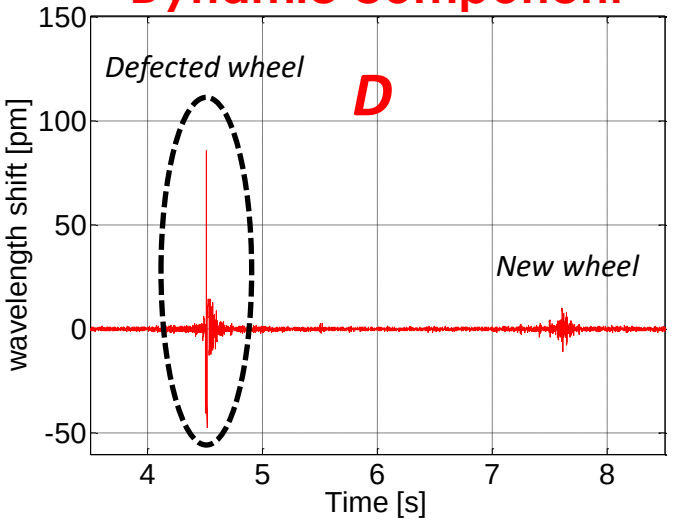
**Static component**




+

**Dynamic component**




*Wheel Weight*

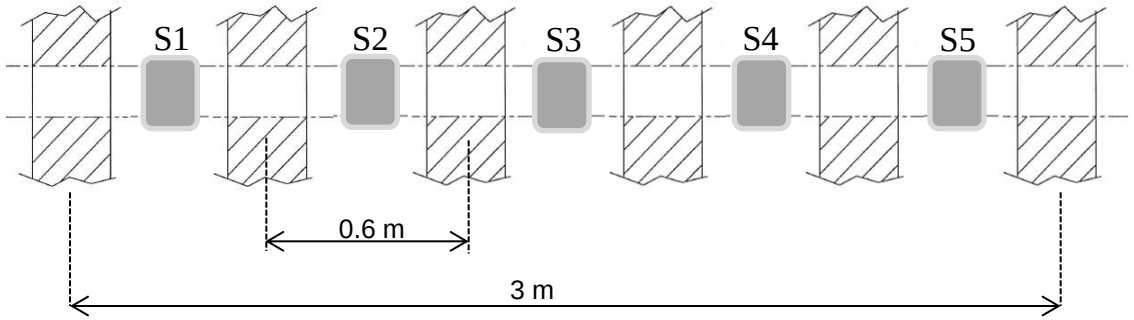
***Dynamic Impact force and defected wheel identification***

**No needs for additional hardware components**

# Wild Functionality Implementation

✓ **Five Sensors per track**

✓**60cm Sensor distance to cover the entire wheel envelope**




Marcianise – Maddaloni Site

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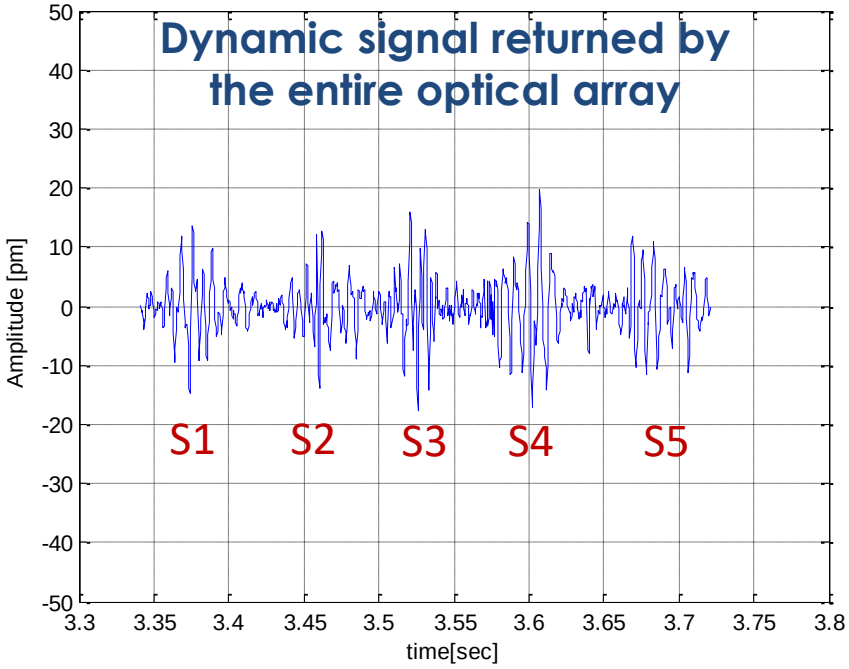
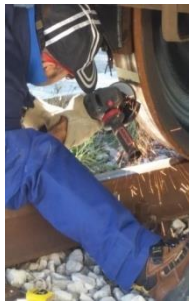
GRUPPO FERROVIE DELLO STATO




✓ The reconstruction of the entire profile of each wheel is obtained by "merging" the five responses returned by the sensors in their respective regions of influence

✓ The number of sensor can be extended to cover different wheel envelopes

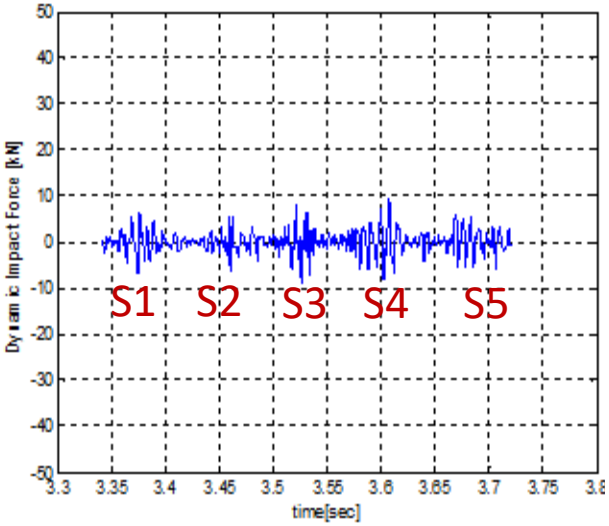
# Impact Force: Preliminary validation tests



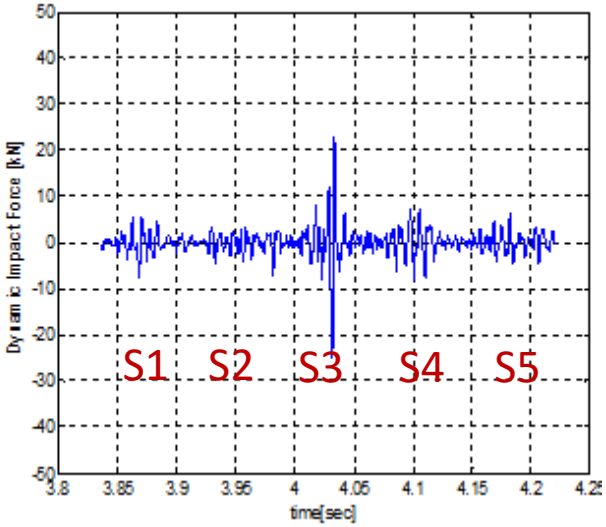
Transits of a test car with two axles in the following configurations:

1. New Wheels without defect
2. Wheels with 39 mm long defects
3. Wheel with 76 mm long defects

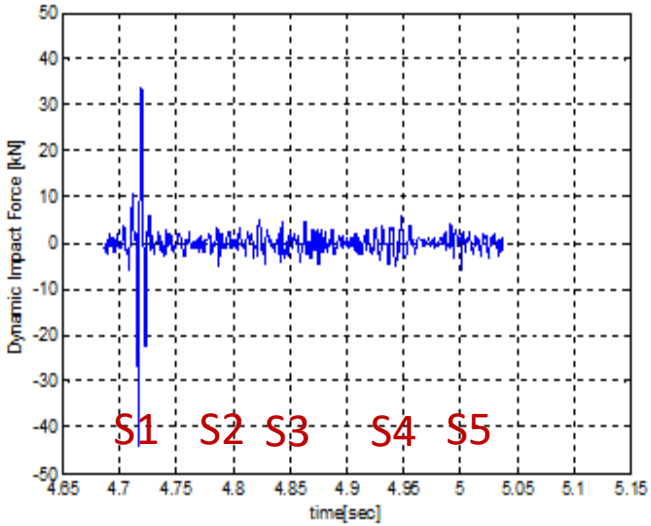
## New Wheel




## Flat Wheel L=39 mm




## Flat Wheel L=76 mm

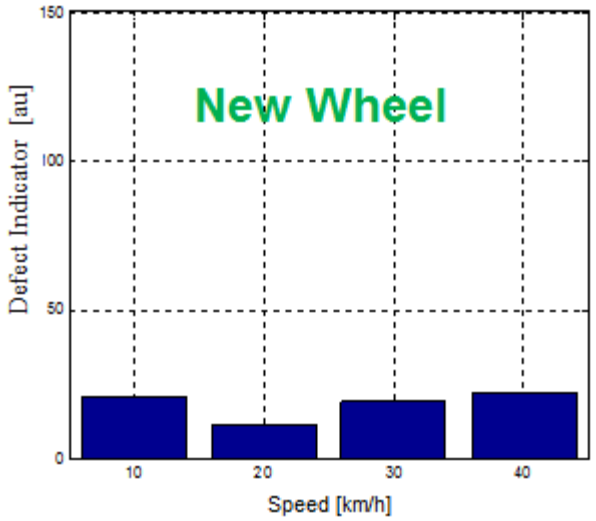



Dynamic **IMPACT FORCE** as function of the defect length
for a train speed of 30 km/h

# "Defect Indicator (DI)"

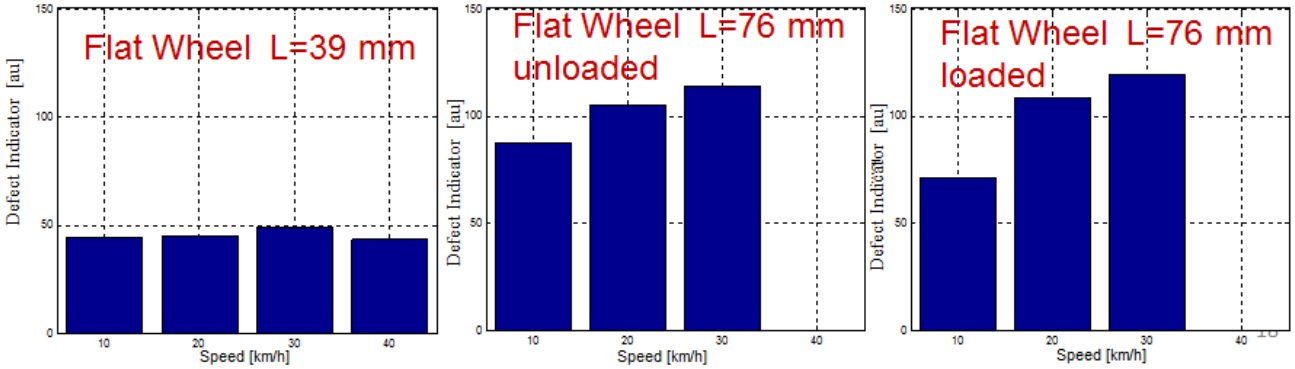
- The Dynamic impact force exerted by a given wheel also depends on wheel weight and train speed

- To provide an observable output able to identify defected wheels taking into account both weight and speed, a **Defect Indicator** was introduced by normalizing the dynamic impact force:




**Defect Indicator (DI)**

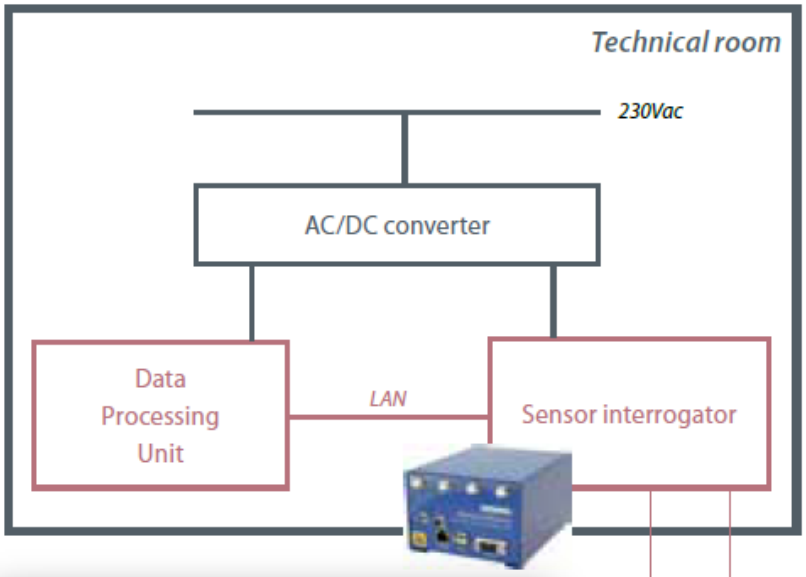
$$D_N = \frac{D}{f(P,v)}$$



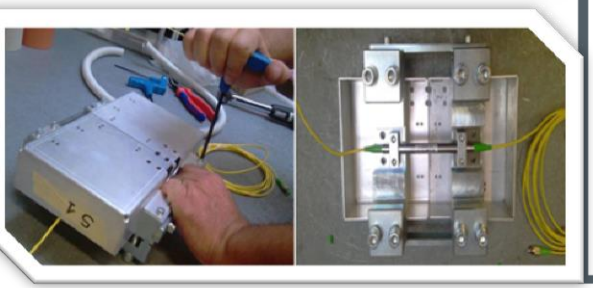

The unloaded car has a weight of approximately 13 tons.
The loaded car has a weight of approximately 23 tons.

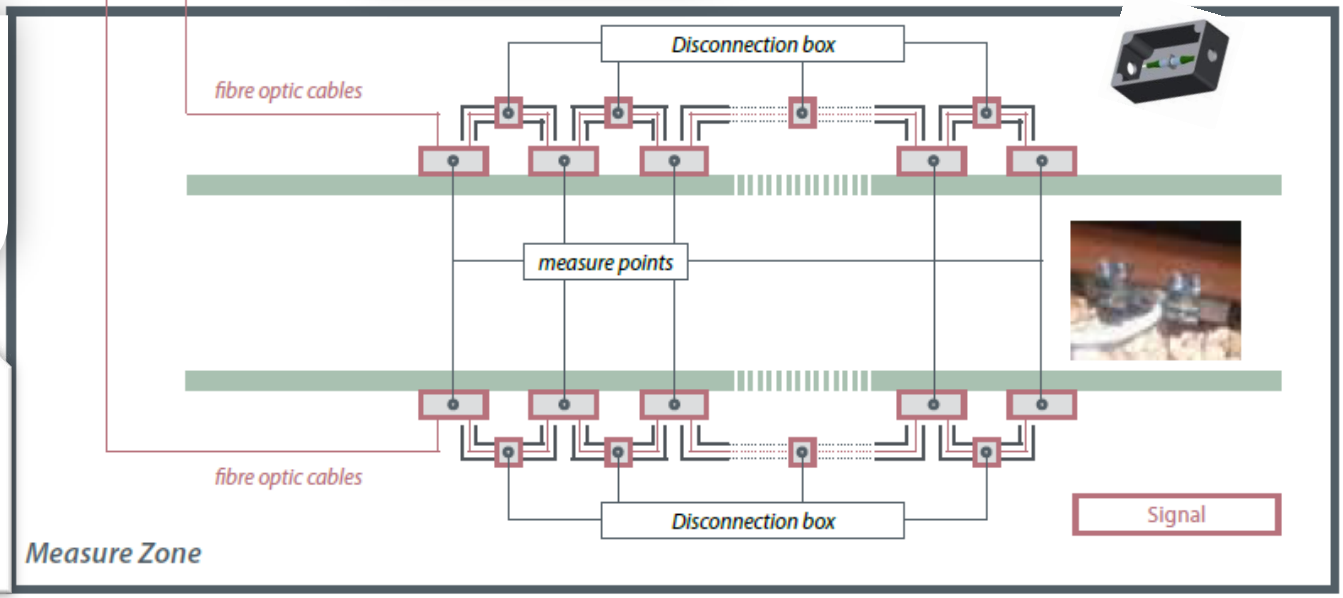
# The architecture of the WIM & WILD System

## The Project Demonstrator




EAV Garibaldi Central Station Naples (Italy)

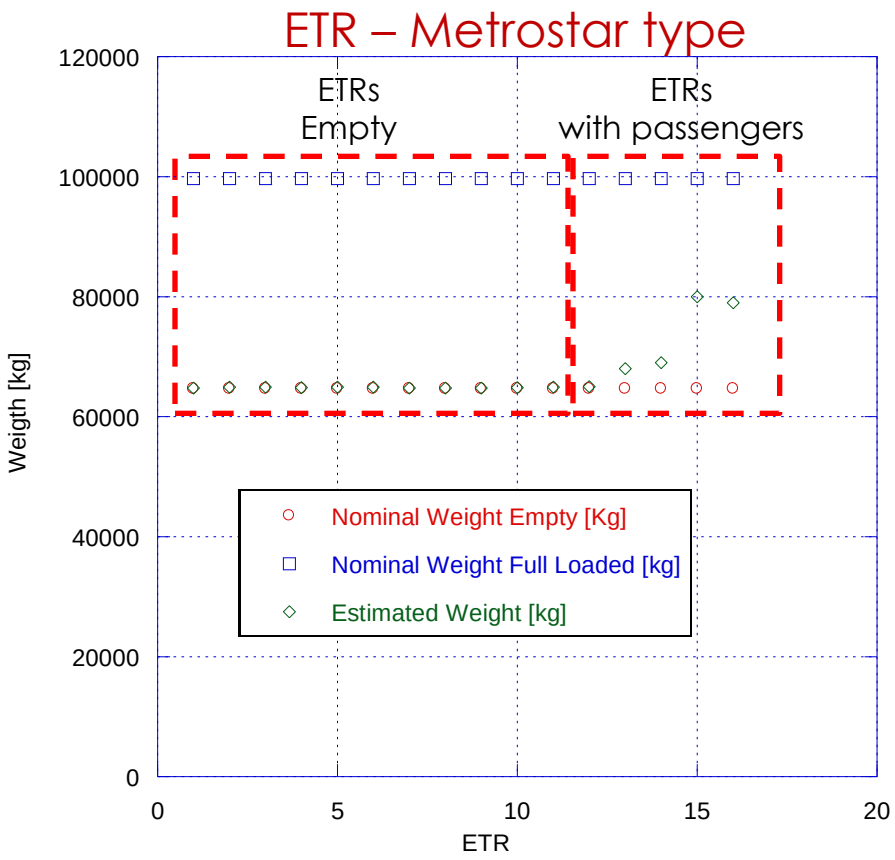


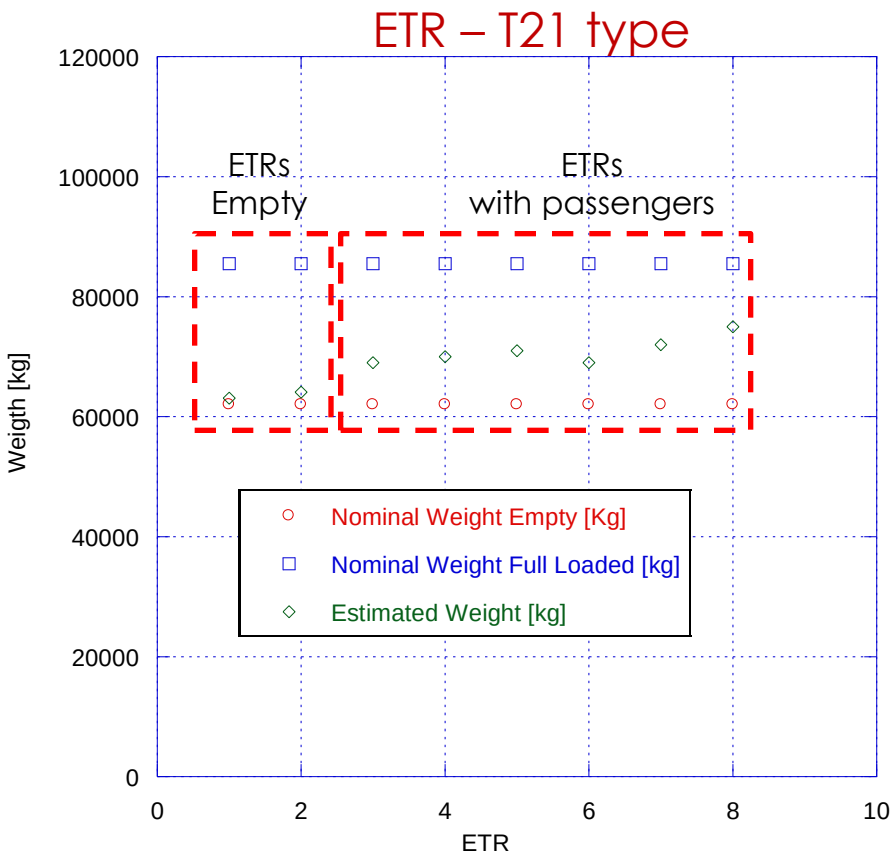
# WIM Tests

## Experimental trials in EAV Garibaldi Central Station Naples (Italy)

E.A.V.

### Load tests on ETRs in normal operative conditions (Empty ETRs or ETRs with passengers)



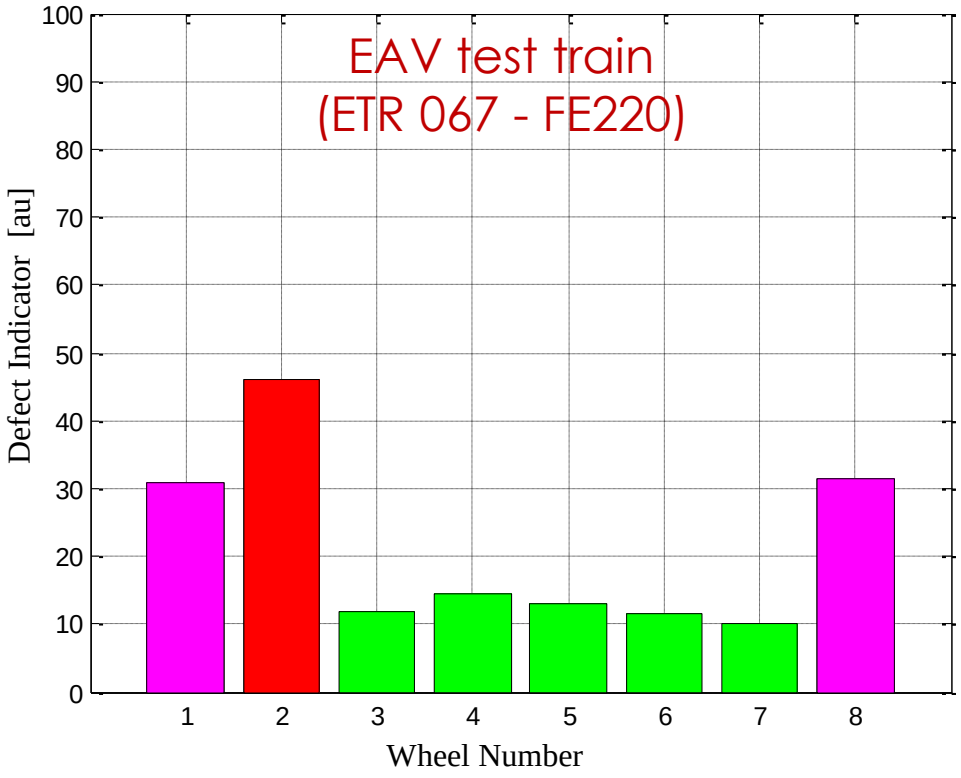
# In field validation tests

## Experimental trials in: EAV Garibaldi Central Station Naples (Italy)

E.A.V.

**Defect Indicator VS Laser scanning probes directly operated on the train wheels**

### WILD Defect Indicator

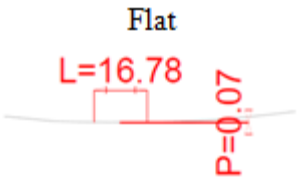



### Scanner laser measurements (EAV)

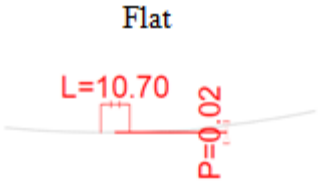
**Wheel without defect (Wheels: 3, 4, 5, 6, 7)**

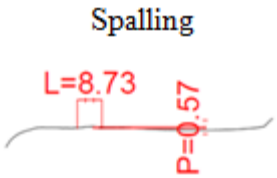
**defected wheel : ~ 25 mm flat (Wheels: 1, 8)**

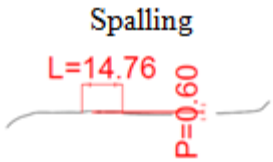
**Wheel 1**




**Wheel 8**

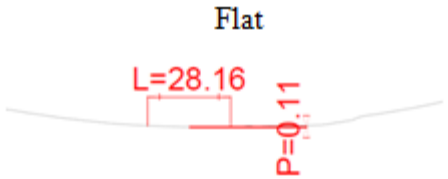



**defected wheel : ~ 28 mm flat (Wheel: 2)**

**Wheel 2**



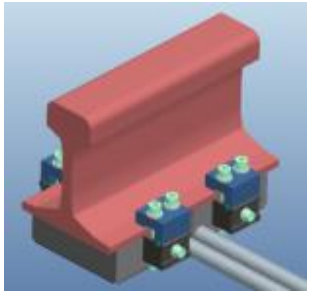

**… the system's result are in agreement with the measurements returned by the scanner laser probe !!!**

# The IN2W System

## IN2W System: Functionalities

A novel WIM-WILD fiber optic monitoring system has been designed, developed and successfully tested and validated in real environments

- System functionalities include: Axle counting, Train composition identification, Train speed and acceleration measurements, Weighing in motion, Dynamic Impact force detection, Defected wheels identification



## IN2W System: Features and Specifications

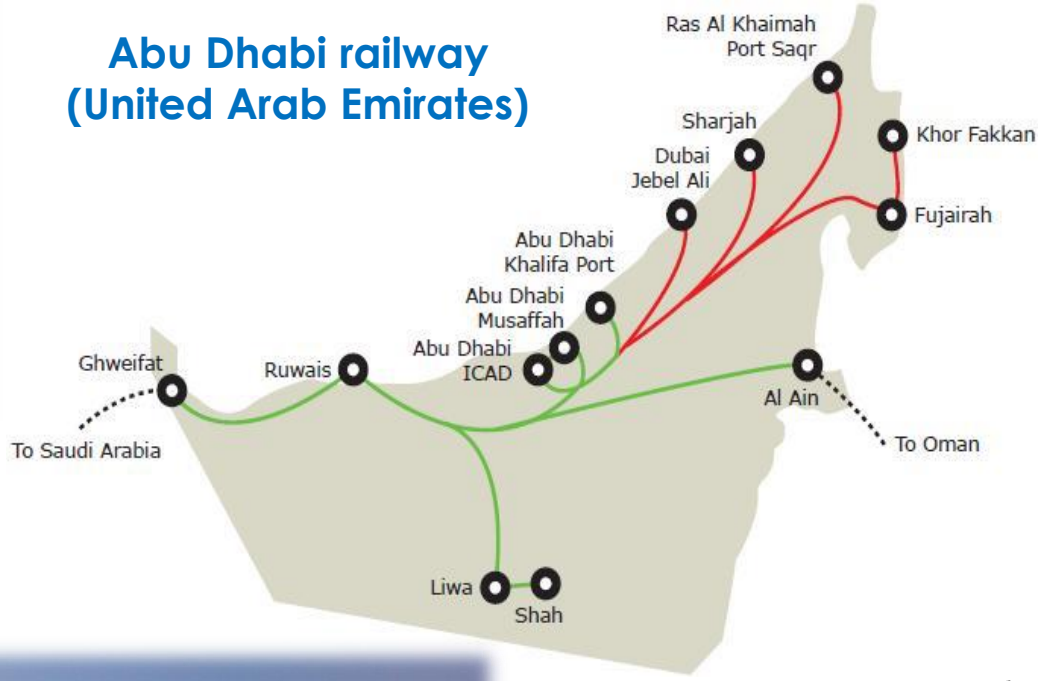
- **WIM & WILD accuracy: 2%** - speed range 5-120Km/h (expected **speed range of 5-350 km/h)**
- **Non invasive installation** The installation doesn't require modification of existing track structure and no specific foundation is needed. Applicable at any type of rail infrastructure (UNI50, UIC60, etc …).
- **Fault tolerance:** the system redundancy is implemented to allow correct operation also in case of 50% sensor failures

- **Absence of electrical equipment and connections:** all the components close to the rails are based on optical fiber technology and does not require any electrical connection
- **Installation in harsh environmental conditions:** wide range of **operating temperatures (-40 °C; + 85 °C)**, high level of resistance to moisture, vibration, dust, sand.
- **Certifications:** European Norm EN50125-3 and IS402.
- **Auto-Diagnostics:** The system is equipped with auto-calibration features combined with a full auto-diagnostic architecture able to continuously check the correctness of the measurements, the integrity of the different components of the system

# From Research towards Pre-Industrialization

3 WIM systems are now installed in the United Arab Emirates

## Abu Dhabi railway (United Arab Emirates)





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