The sustainable freight railway: Designing the freight vehicle – track system for higher delivered tonnage with improved availability at reduced cost

SUSTRAIL

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EXECUTIVE SUMMARY

SUSTRAIL aims to increase network capacity to enable higher delivered tonnage of freight. This will be achieved by developing novel, sustainable technologies for infrastructure (***Work Package 4: Sustainable Track***) and for freight vehicles (***Work Package 3: The Freight Train of the Future***) to allow operation with higher axle loads or at faster speeds. Increasing the line speed of freight trains will help to free up capacity on mixed passenger-freight lines.

A selection of the technologies developed in SUSTRAIL will be demonstrated in ***Work Package 6: Technology Demonstration*** at the test track in Romania.

The objective of ***Work Package 1: Benchmarking*** is to provide a benchmark of the current freight 'system', i.e., to establish the existing 'zero state' for subsequent comparative and enhancement activities. ***Tasks 1.1 – 1.5*** have focussed on data collection: Deliverable D1.2 provides an overview of the three selected routes (in Bulgaria, Spain and the UK) in SUSTRAIL and their general characteristics; Deliverable D1.4 examines the infrastructure properties in more detail; and Deliverable D1.5 studies freight operations in the three countries and along the routes. Deliverable D1.3 presents data on the most common freight vehicles currently in operation in Bulgaria, Spain and the UK, and also Romania. Much of this is summarised in Deliverable D1.1.

Task 1.6 Telemetry of Test Site and Vehicle is a separate work stream that provides groundwork for activities in ***Work Package 6: Technology Demonstration***. Deliverable D1.6 has two principal themes: (1) an overview and assessment of the test track in Romania; and (2) initial planning or work and methods to benchmark the performance of the whole system (track and vehicle) and assess performance of the upgraded system in ***WP6***. This assessment and performance benchmark will be used in ***WP6*** to validate the improved performance of the upgraded vehicle and track.

Based on freight vehicle data collected in ***Task 1.3***, an open high-sided wagon (Class E, UIC 571-2) was selected to evaluate testing capabilities at the AFER's Testing Centre at Faurei, Romania, the test track that will be used in ***WP6***. The following measurements were made:

- Static brake tests
- Dynamic brake tests, unloaded, at 100 km/h and 120 km/h
- Noise measurements at 100 km/h and 120 km/h
- MiniProf wheel profile measurements of the test wagon before and after the dynamic brake tests
- MiniProf rail profile measurements at a number of selected locations
- Track gauge and cant measurements at a number of selected locations

These tests and measurements are described in detail in Deliverable D1.6, along with a description of other technologies that may be developed in SUSTRAIL and used to support measurement, telemetry and performance evaluation.

The main ***conclusions regarding the preliminary tests and analysis of testing possibilities on the test track*** are:

- The AFER test track at Faurei, which was recently modernised, offers good conditions for future SUSTRAIL demonstration activities, allowing a wide range of standard tests, especially those required for modified or new vehicles.
- For the scientific purposes of SUSTRAIL project, some other valuable testing procedures and equipment have been proposed. If implemented, these tests would offer a wider variety of data, at different detail levels, which would enable useful comparisons within vehicle benchmarking.

Table of Contents

1. INTRODUCTION 8

2. TESTING FACILITIES AND PROCEDURES 9

2.1 Test Track 9
2.2 Test Vehicle 10
2.3 Other Testing Facilities on Selected Routes (UK, Spain and Bulgaria) 10
2.4 Test Procedures and Regulations 11

3. TESTS OF VEHICLE-TRACK SYSTEM ON THE TEST TRACK 13

3.1 Vehicle Testing on the Test Track 13
3.1.1 Braking System Testing 13
3.1.2 Noise Level Measurements 19
3.1.3 Wheel Profile Measurements 22
3.2 Infrastructure Measurements on the Test Track 29
3.2.1 Track Measurements 29
3.2.2 Track Profile Measurements 32
3.3 Other Testing Possibilities 37
3.3.1 Tests proposed by MERMEC 37
3.3.2 Tests proposed by TRAIN 40

4. PERFORMANCE BENCHMARK OF KEY VEHICLE COMPONENTS AND INFRASTRUCTURE 45

4.1 Vehicle Benchmark 45
4.2 Infrastructure Benchmark 46

5. CONCLUSIONS AND FUTURE WORK 49

APPENDICES 51

Appendix 1. Infrastructure measurement technology (Network Rail) 51
Appendix 2. Sensing technologies for railway monitoring and telemetry 59
Appendix 3. Romanian S78 Wheel Profile 63

REFERENCES 64

List of Tables

TABLE 1 STATIC BRAKE TESTING RESULTS – MEASURED PARAMETERS VERSUS RECOMMENDED VALUES 14
TABLE 2 RESULTS OF DYNAMIC BRAKE TESTING (UIC 544-1) 17
TABLE 3 CALCULATION OF THE RATIO OF BRAKED WEIGHT (UIC 544-1) 18
TABLE 4 WHEEL PROFILE PARAMETERS – MEASUREMENTS AND CALCULATIONS 24
TABLE 5 TRACK GAUGE AND CANT MEASUREMENTS ON SECTION A. (KM 0+340) 29
TABLE 6 TRACK GAUGE AND CANT MEASUREMENTS ON SECTION B. (KM 0+424) 30
TABLE 7 TRACK GAUGE AND CANT MEASUREMENTS ON SECTION C. (KM 12.970+30) 31
TABLE 8 RESULTS OF RAIL TRACK PROFILE MEASUREMENTS 35
TABLE 9 RIDE QUALITY PARAMETERS 37
TABLE 10 EVALUATION OF FBG AND BRILLOUIN FIBRE OPTIC SENSING TECHNOLOGIES 43
TABLE 11 NETWORK RAIL - GEOMETRY QUALITY BAND STANDARD DEVIATIONS [MM] 48
TABLE 12 SPECIFICATIONS FOR TESTING FREQUENCIES IN ULTRASONIC RAIL INSPECTIONS 53
TABLE 13 WHEELCHEX WHEEL IMPACT LOAD DETECTOR (WILD) SITES 55
TABLE 14 EXAMPLE OF MEASURED UNEVEN LOADING (WHEELCHEX RAIB REPORT 02/2009) 56
TABLE 15 SENSOR TYPES AND MEASURING CAPABILITIES 61
TABLE 16 SENSORS' SENSITIVITY DEPENDENCE ON ENVIRONMENTAL CONSTRAINTS 61

List of Figures

FIGURE 1 AFER'S RAILWAY TESTING CENTRE AT FAUREI 9
FIGURE 2 TEST VEHICLE - EAOS ORDINARY OPEN HIGH-SIDED WAGON (UIC 571-2) 10
FIGURE 3 BRAKE CYLINDER PARAMETERS IN P (PASSENGER) BRAKING REGIME 14
FIGURE 4 BRAKE CYLINDER PARAMETERS IN F (FREIGHT) BRAKING REGIME 15
FIGURE 5 MEASUREMENT OF BRAKING FORCES ON THE WHEEL 16
FIGURE 6 LOCATION OF EXPERIMENTAL SET UP FOR NOISE LEVEL MEASUREMENTS ON THE TEST TRACK 19
FIGURE 7 EXPERIMENTAL SET UP (POSITIONING OF EQUIPMENT FOR NOISE LEVEL MEASUREMENTS - STANDARD STAS 6661-82, SUPERSEDED BY EN ISO 3095:2005) 20
FIGURE 8 SOUND LEVEL METER RION NL-32 USED FOR NOISE LEVEL MEASUREMENTS 20
FIGURE 9 MEASUREMENTS OF NOISE LEVEL ON VEHICLE WITH CONSTANT SPEED OF 100 KM/H 21
FIGURE 10 MEASUREMENTS OF NOISE LEVEL ON VEHICLE WITH CONSTANT SPEED OF 120 KM/H 21
FIGURE 11 MINIPROF STANDARD WHEEL PROFILE MEASURING DEVICE FITTED TO A WHEEL IN POSITION TO MAKE A MEASUREMENT 22
FIGURE 12 DIMENSIONS DEFINING MEASUREMENT OF THE *WHEEL WEAR* PARAMETER 25
FIGURE 13 SCALE PLOT EXAMPLE INDICATING THE DIMENSIONS USED TO CALCULATE THE WHEEL HOLLOWING PARAMETER 26
FIGURE 14 EXAMPLE OF WHEEL PROFILE MEASUREMENT PLOTTED AGAINST THE S78 REFERENCE PROFILE (WHEEL 1 OF THE TEST VEHICLE MEASURED BEFORE THE DYNAMIC BRAKE TESTING) 26
FIGURE 15 EXAMPLE OF WHEEL PROFILE MEASUREMENT PLOTTED AGAINST THE S78 REFERENCE PROFILE (WHEEL 7 OF THE TEST VEHICLE MEASURED BEFORE THE DYNAMIC BRAKE TESTING) 26
FIGURE 16 EXAMPLE OF WHEEL PROFILE MEASUREMENT PLOTTED AGAINST THE S78 REFERENCE PROFILE (WHEEL 8 OF THE TEST VEHICLE MEASURED BEFORE THE DYNAMIC BRAKE TESTING) 26
FIGURE 17 EXAMPLE OF TWO PROFILES PLOTTED TOGETHER (WHEEL 3 OF THE TEST VEHICLE AFTER THE DYNAMIC BRAKE TESTING) 27
FIGURE 18 WHEEL FLAT AFTER THE DYNAMIC BRAKE TESTING (THE WHEEL FLAT IS IN THE LOWER RIGHT QUARTER OF THE PICTURE, THE FLANGE IS TOWARDS THE TOP LEFT) 28
FIGURE 19 TEST TRACK WITH THE *'SWITCH AND CROSSING'* MEASUREMENT LOCATIONS 1 TO 5 33
FIGURE 20 CLOSE UP VIEW OF PART OF THE *'SWITCH AND CROSSING'* MEASUREMENT LOCATION, SHOWING MEASUREMENT LOCATIONS 1 TO 3 33
FIGURE 21 SMALL CONCRETE BRIDGE ASSOCIATED WITH MEASUREMENT LOCATIONS 6-8 (LOCATIONS 6, 7 LABELLED 34
FIGURE 22 PLOT OF THE UIC60 REFERENCE PROFILE AND THE PROFILE MEASURED AT LOCATION I2 36
FIGURE 23 PLOT OF THE UIC60 REFERENCE PROFILE (UPPER LINE) AND THE PROFILE MEASURED AT LOCATION I7 (LOWER LINE) 36
FIGURE 24 EXAMPLE OF RIDE QUALITY ACCELEROMETERS SET UP 38
FIGURE 25 MER MEC GROUP RAIL PROFILE MEASUREMENT SYSTEM 38
FIGURE 26 MER MEC GROUP V-CUBE 39
FIGURE 27 TYPES OF WHEEL DEFECTS WHICH CAN BE DETECTED WITH *MER MEC GROUP WHEEL SURFACE DEFECTS* 39
FIGURE 28 EXAMPLE OF W-INSPECT SET UP 40
FIGURE 29 OPERATING FREQUENCY RANGE OF DIFFERENT TYPES OF SENSORS 41
FIGURE 30 FIBRE OPTIC SENSORS (FSO) IN MONITORING AND TELEMETRY OF BOTH TRACK AND VEHICLE [8] 42
FIGURE 31 EXPERIMENTAL TRACK MONITORING USING DIFFERENT FOS [5] 42
FIGURE 32 EXPERIMENTAL TRACK MONITORING USING FBG FOS 43
FIGURE 33 EXAMPLE OF AN INTEGRATE SATELLITE/INERTIAL SYSTEMS FOR TELEMETRY PURPOSE [7] 44
FIGURE 34 NEW MEASUREMENT TRAIN (COPYRIGHT NETWORK RAIL) 51
FIGURE 35 SOUTHERN MEASUREMENT TRAIN (EURAILSCOUT UFM160) 52
FIGURE 36 EXAMPLE OF GROUND PENETRATING RADAR OUTPUT 54
FIGURE 37 EXAMPLE OF WHEELCHEX OUTPUT (RAIB REPORT 02/2009) 56
FIGURE 38 THE GOTCHA SYSTEM INSTALLED ON THE RAIL 57
FIGURE 39 THE GOTCHA SYSTEM INSTALLED AT SHAWFORD ON BML1 NEAR 69.5 MILE POST 57
FIGURE 40 EXAMPLE OF GOTCHA SYSTEM MEASUREMENT USING A SINGLE SENSOR 58
FIGURE 41 VIBRATION MEASUREMENTS' ACCURACY AS WEATHER CONDITIONS FUNCTION 61
FIGURE 42 VIBRATION MEASUREMENTS' ACCURACY DEPENDING ON TEMPERATURE VARIATION 62

1. INTRODUCTION

SUSTRAIL aims to increase network capacity to enable higher delivered tonnage of freight. This will be achieved by developing novel, sustainable technologies for infrastructure (***Work Package 4: Sustainable Track***) and for freight vehicles (***Work Package 3: The Freight Train of the Future***) to allow operation with higher axle loads or at faster speeds. Increasing the line speed of freight trains will help to free up capacity on mixed passenger-freight lines.

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2. TESTING FACILITIES AND PROCEDURES

2.1 Test Track

The selected test track for WP1 and WP6 of SUSTRAIL is AFER's Testing Centre at Faurei, Romania (*Figure 1*).

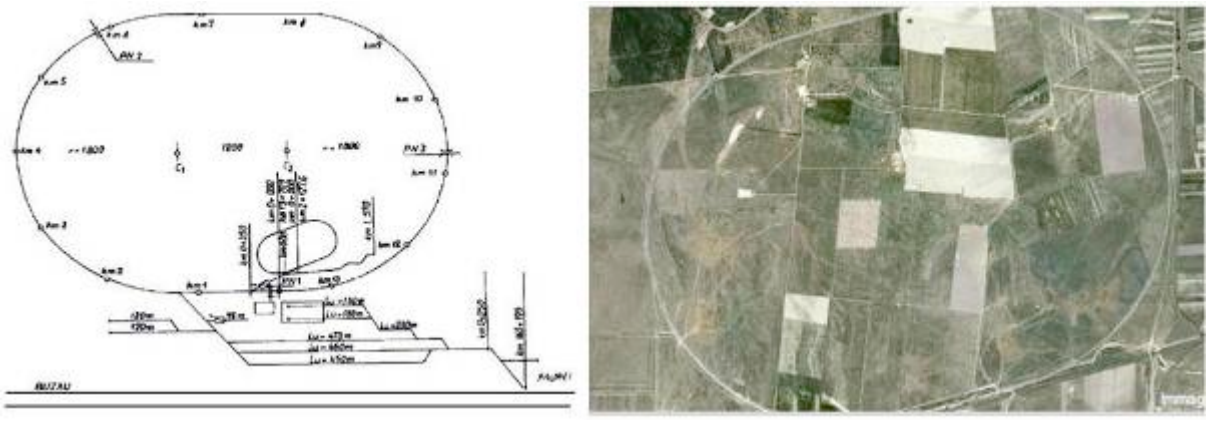


Figure 1 AFER's Railway Testing Centre at Faurei

The testing centre at Faurei has a total length of 20.2 km, interlocking system, and consists of:

- A large ring
  - 13.7 km with 6 footbridges and 4 level crossings;
  - maximum speed 200 km/h;
  - two curves with the radius of 1800 m and the cant of tracks 150 mm;
  - lengths of the straight lines: 1000 m and 950m;
  - electrification in single – phase alternating current of 25 kV/50 Hz with the level of catenary at 5,5 m;
- A small ring
  - 2.2 km with 5 footbridges;
  - maximum speed 60 km/h;
  - curves with radius of 400m (cant of track 70 mm), 180 m (cant of track 70 mm), 250 m (cant of track 70mm), 180 m (cant of track 130mm), 250 m (cant of track 130mm), and 800 m (cant of track 70 mm);
- Functional buildings (workshop, offices and accommodation facilities).

The Railway Testing Centre allows the following testing activities:

- tests for railway traffic safety;
- comfort tests (measurement of vibrations inside the locomotive cabin and passenger compartments, the noise level of railway vehicles, etc.);
- behaviour of vehicles in traffic (rolling resistance, gravity centre, torque etc.);
- braking system testing;
- tests for the environment protection;
- railway infrastructure tests;
- freight transport security tests.

Depending on the facilities, AFER is able to perform other tests according to the clients' requests.

2.2 Test Vehicle

Task 1.3 (Rolling Stock) identified certain classes of vehicles as the most common ones both on selected routes in UK, Spain and Bulgaria, but also with respect to data provided by partners AFER and SIRV from Romania.

Since the activities to decide the future vehicle to be developed within SUSTRAIL, as part of WP2 (i.e., Task 2.4: Future vehicle performance requirements) and WP3 were still on-going, the most common used vehicles identified in Task 1.3 were considered for the initial tests. Taking into account the objectives of these initial tests and the availability of different types of wagons, an open high-sided wagon (Class E, UIC 571-2) was finally prepared and provided by SIRV for the preliminary tests on AFER's test track at Faurei.

The selected wagon for the initial tests *(Figure 2)* has the following main features:

- ***Class:*** E Ordinary open high-sided wagon (UIC 571-2)
- ***Type:*** EAOS
- ***UIC identification:*** 31 53 5301 456-8
- ***Specifications:*** four axles, brake platform, Y25 bogies, max. speed: 120 km/h unloaded, 100 km/h loaded



Figure 2 Test vehicle - EAOS Ordinary open high-sided wagon (UIC 571-2)

2.3 Other Testing Facilities on Selected Routes (UK, Spain and Bulgaria)

One of the objectives of Task 1.6 is to perform a benchmark of the track performance on the selected routes in UK, Spain and Bulgaria. The final demonstration in WP6 should evaluate the novel technical solutions resulting from WP4 and implemented on the same locations where the track performance is to be initially measured and described.

The infrastructure manager partners in SUSTRAIL have analysed their existing equipment in operation on the selected routes, and proposed several methods and techniques to capture the relevant characteristics defining the track performance. The main testing facilities and equipment in operation, which were proposed, are mentioned briefly below.

Network Rail (NR) proposed measurement technology consisting of:

- Network Rail New Measurement Train (NMT)
- Network Rail Southern Measurement Train (UFM160)
- Network Rail Track Recording Unit (TRU)
- Network Rail Ultrasonic Test Units (UTU)
- Ground Penetrating Radar
- 'WheelChex' - Wheel Impact Load Detector
- Gotcha Asset Management System

More technical details, features and specifications of above measurement technology are presented in *Appendix 1.* Infrastructure measurement technology (Network Rail)

All above systems are in operation on the selected UK routes. Along the two strategic freight routes from Southampton and Felixstowe to Warrington, via Nuneaton, there are ***five wheel impact test sites:***

Monitoring System	***Site***	***Location***
Gotcha	Shawford	BML1 near 68mils 50ch
WheelChex	Cholsey	MLN1 at 45 miles 9ch
Gotcha	Banbury	DCL at 86 miles
WheelChex	Eastrea	EMP at 93m 59ch
WheelChex	Thurmaston	SPC5 at 101m 78ch

There is also a WheelChex system at Heaton Chapel on a part of the West Coast Main Line that leads towards Manchester. This is traversed by passenger and freight trains. There is also a mobile Gotcha system which can be reasonably quickly installed at a location. Data from the Banbury site is used most frequently by Chiltern Railways.

Work is on-going in SustRail to identify similar monitoring and measuring technologies and measurement locations on the selected routes in Spain and Bulgaria. Depending on the measurement and monitoring systems available on routes in Spain and Bulgaria, the final benchmark methodology will have to select the relevant common parameters characterising the track performance and the locations where the track should be monitored[1].

2.4 Test Procedures and Regulations

In the UK, new and modified rail vehicles need to comply with the Railway Group Standard GM/RT2000 "Engineering acceptance of rail vehicles" [9]. This describes the procedures that would need to be complied with for design and acceptance. On testing, Section §6.10 lists some of the requirements:

"Type Conformance Tests fall into the following categories:

a) Tests that are not specific to the rail industry and in which the essential knowledge relates to the specialism rather than the application (for example, component life testing);

b) Tests that are specific to the rail industry and in which specialist knowledge of the railway environment is essential. Such tests include, but not exclusively:
- *Vehicle ride tests;*
- *Track force tests;*
- *δQ/Q tests;*
- *Brake tests (parking brake and dynamic tests);*

[1] Ideally, track locations selected for periodic monitoring should have similar characteristics to the eventual site on the test track where the novel infrastructure technologies developed in Work Package 4 will be demonstrated in Work Package 6.

- *Bogie rotation tests;*
- *Pantograph sway and pantograph forces tests;*
- *Vehicle sway tests.*

Type Conformance Tests within this category shall only be carried out by suppliers qualified under the principles described in GM/RT2450 as competent and experienced in the carrying out of testing of such components."

The standards EN 14363:2005 [3] and EN 12663-2:2010 [1] provide details also on the types of tests that would be required for a new or modified vehicle to be accepted. The standard for brake tests for freight vehicles in the UK is GM/RT2043 [10].

The main tests to be carried out on AFER's test track have to comply with all European and national regulations in the domain. The most representative available regulations which should be followed are the UIC leaflets and European standards (EN). Such standards were already considered during the preliminary tests for brake system testing, measurement of wheels and track profiles and other characteristics, noise measurement, etc.

However, in some cases such regulation does not exist or is not applicable (experimental new testing procedures, superseded standards, testing conditions different from standard, etc.). In such cases, the most suitable and applicable regulation, such as national standards, company standards and procedures, etc., has to be identified and applied. If, eventually for new testing methods, no regulation is available the project partners will consider developing basic test norms.

3. TESTS OF VEHICLE-TRACK SYSTEM ON THE TEST TRACK

3.1 Vehicle Testing on the Test Track

3.1.1 Braking System Testing

All braking tests were carried out on the selected wagon, type EAOS, presented above.

The testing methods, measuring equipment and interpretation of results followed the standard procedures, as regulated by UIC leaflets UIC 540, 541-1 and 544-1, and by national standard SR 12300-98.

The selected tests of the braking system which were performed are part of the mandatory testing procedures for the homologation and authorisation of new or evolved design vehicles, as well as repaired or modernised ones. The testing of the braking system included:

- ***Static brake tests:*** consisting of (i) measurement of brake cylinder parameters, and (ii) static efficiency of the brake linkage;
- ***Dynamic brake tests:*** consisting of measurements of the braking distance and determining the braked weight percentage.

3.1.1.1 Static Brake Testing

A. Measurement of Brake Cylinder Parameters (air pressure, filling and emptying times)

Air pressure in the brake cylinder, and its filling / emptying times are essential parameters in the assessment of a railway vehicle braking system. According to UIC regulations (UIC Leaflet 540), these parameters have to meet the required values, given within the leaflet. The dimensioning of the brake cylinder should consider these parameters (the recommended values) in the case of emergency braking as well.

These parameters were measured using pressure transducers mounted on the brake cylinder and the main brake pipe. The signals captured by these transducers were recorded against time on a computer equipped with a specialised data acquisition interface.

The procedure consisted of performing emergency brakes and releases; the pressure variation in the brake cylinder and absolute values of the compressed air pressure were measured during these cycles. The values which were determined for different braking regimes (passenger / freight), according to the recorded parameters, are presented in *Figure 3* and *Figure 4* below.

The parameters determined for the ***P (passenger) braking regime*** *(Figure 3)* are:

- Maximum air pressure in the brake cylinder: 3.75 bars
- Filling time of the brake cylinder (up to 95% of the maximum pressure): 4.1 s
- Release / emptying time (to 0.4 bar): 15.6 s

The parameters determined for the ***F (freight) braking regime*** *(Figure 4)* are:

- Maximum air pressure in the brake cylinder: 3.81 bars
- Filling time of the brake cylinder (up to 95% of the maximum pressure): 24.4 s
- Release / emptying time (to 0.4 bar): 43.8 s

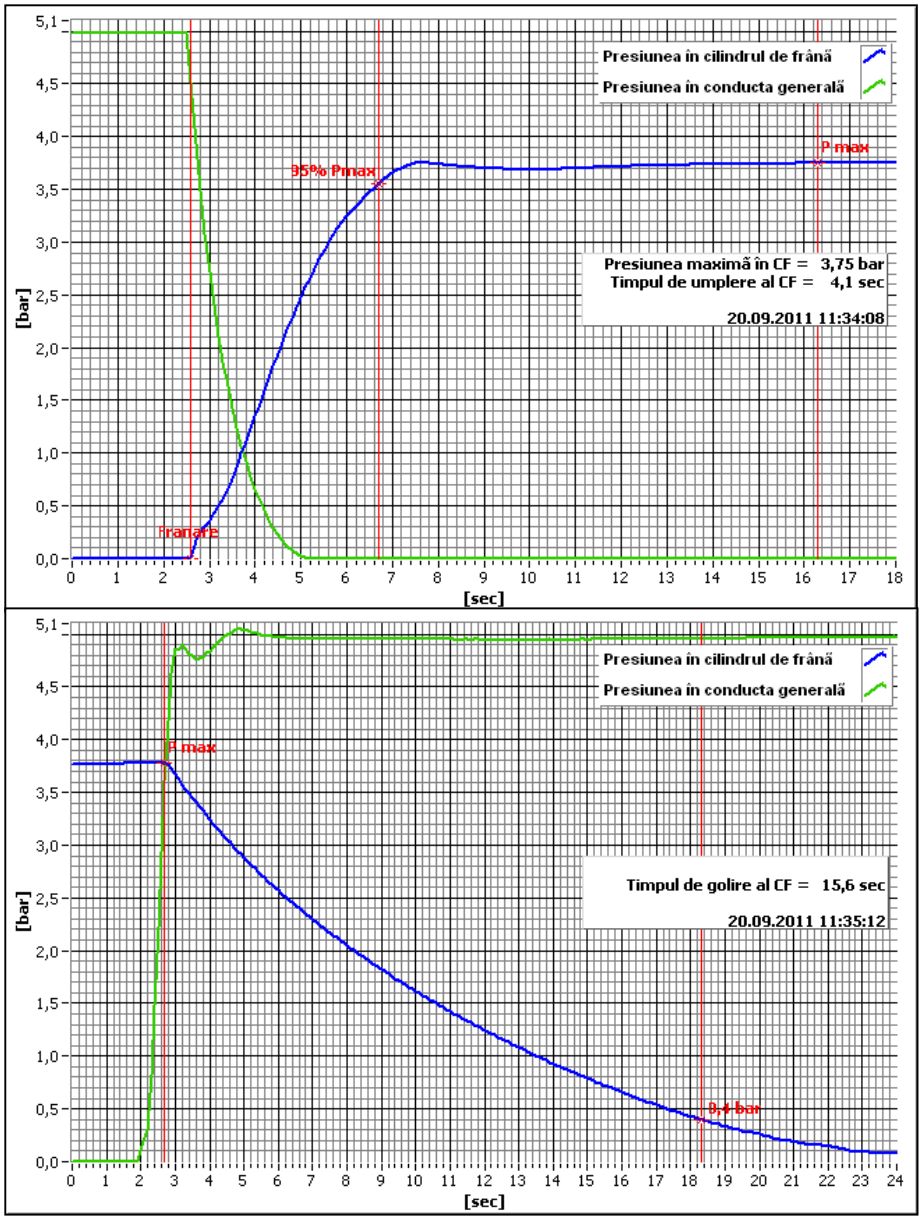


Figure 3 Brake cylinder parameters in P (passenger) braking regime

The measured parameters were compared with the reference values recommended by leaflet UIC 540, as shown in *Table 1* below. All parameters comply with the standard limit values.

Table 1 Static brake testing results – measured parameters versus recommended values

Parameter / Braking regime	Meas. unit	Measured values (load)	Measured values (unload)	Limit values (UIC 540)
Filling time of the brake cylinder / P (passenger) braking regime	s	4.1	4.1	[3 - 5]
Release (emptying) time / P (passenger) braking regime	s	15.6	15.6	[15 - 20]
Filling time of the brake cylinder / F (freight) braking regime	s	24.4	24.4	[18 - 30]
Release (emptying) time / F (freight) braking regime	s	43.8	43.8	[45 - 60]
Maximum air pressure in the brake cylinder (P / F regime)	bar	3.75/3.81	3.75/3.81	[3.8 ± 0.1]

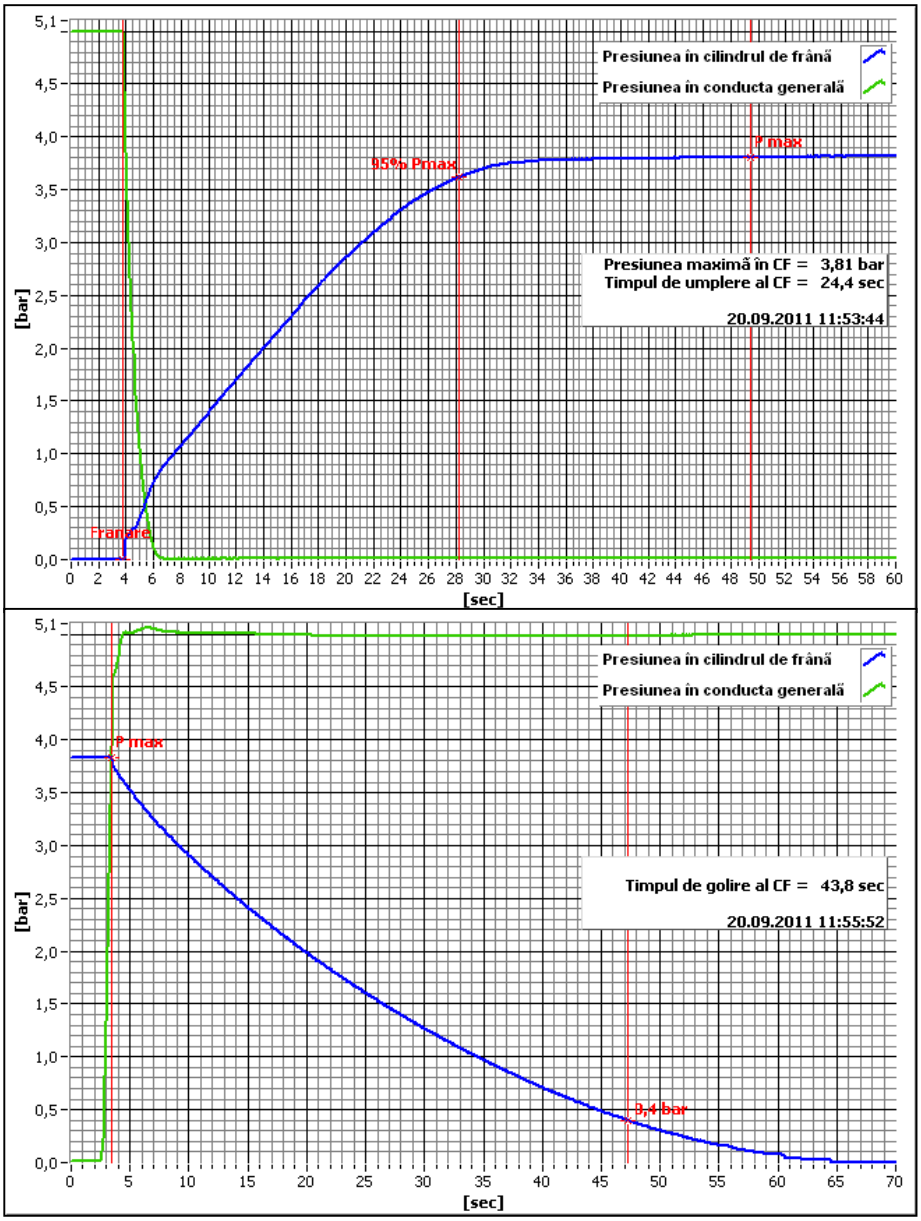


Figure 4 Brake cylinder parameters in F (freight) braking regime

B. Static Efficiency of the Brake Linkage

The brake linkage was tested by measuring the pressure force of the brake shoe on the wheels when activating the brake. The measurement was done using specialised force transducers mounted on the shoe brake instead of the brake block (*Figure 5*). The ratio of measured value to the theoretical, calculated one determines the efficiency of the brake linkage.

The measurements were performed in P (passenger) braking regime for both the empty and the load wagon. Some measurements were also made while the hand brake was applied. The theoretical total pressure force of the shoe on the wheel can be calculated as:

$$\sum F_{dyn} = \eta_{dyn} (i_G F_t - i^* F_R) \quad (1)$$

where:

ΣF_{dyn} total pressure force of the shoe on the wheel [kN];
F_t the force applied to the brake piston rod [kN];
F_R opposite effort due to the brake pressure regulator (usually ~2kN);
η_{dyn} the average efficiency of the brake linkage for running vehicle (the standard value for the braking system of the selected wagon is 0.83 – annex O, UIC 540 leaflet);
i_G the total amplification factor of the brake linkage;
i^* the amplification factor of the 2nd part of the brake linkage (the usual values are 4 for wagons with 2 axles and 8 for wagons with bogies).

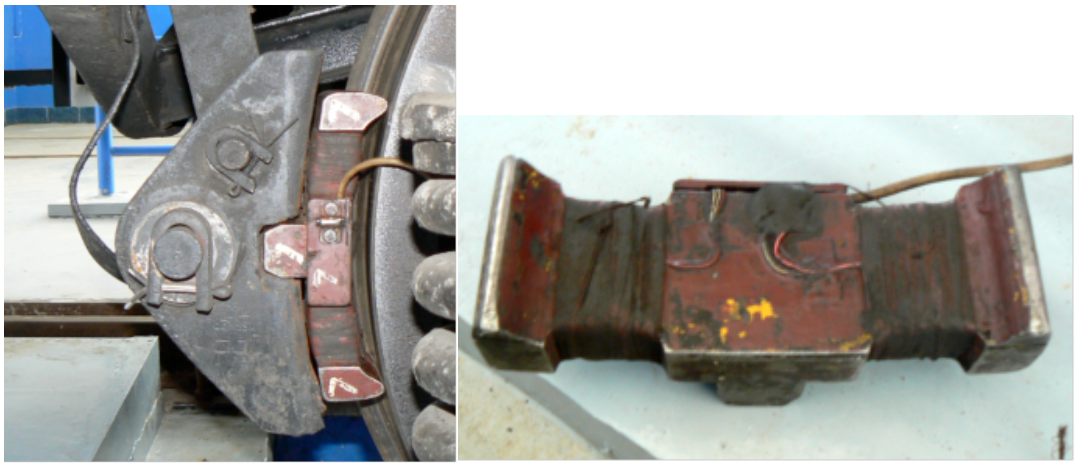


Figure 5 Measurement of braking forces on the wheel

The test results are presented below.

Empty wagon – automatic brake

Air pressure in brake cylinder	3.75 bar
Total braking force (measured value)	147.53 kN
Total braking force (calculated value)	192.38 kN
Static efficiency	76.7 %

Load wagon – automatic brake

Air pressure in brake cylinder	3.75 bar
Total braking force (measured value)	395.90 kN
Total braking force (calculated value)	520.03 kN
Static efficiency	76.1 %

With hand brake applied

Total braking force (measured value)	101.28 kN
Static efficiency	17.1 %

The static efficiency of the automatic brake linkage is slightly below the imposed threshold of 80 % (according UIC 544-1 and SR 12300/98) for both the empty and load wagon. The same situation was observed for the static efficiency when the hand brake is applied (17.1 %, slightly below 20 %, the standard recommended limit).

3.1.1.2 Dynamic Brake Testing

The dynamic brake tests were performed on the test track, on a special line for railway vehicle testing in similar conditions to those in current operation.

The train comprised an electric locomotive, the laboratory wagon fitted with the control and measurement equipment, and the test wagon at the end. The tests were performed according to the standard conditions in UIC Leaflet 544-1. The test wagon was isolated by decoupling it at speed values imposed by the standard, immediately followed by its emergency braking (actuated at the point of decoupling, using a special device). The braking distance is measured after the wagon stops, using the equipment on the laboratory wagon.

According to UIC Leaflet 544-1, 4 tests should be carried out for each different value/parameter characterising the system, respectively: I. Braking regime; II. Speed; III. Load condition (loaded/unloaded). The selected wagon, type EAOS, was tested in the following conditions (UIC 544-1 and SR 12300/98):

I. P (passenger) braking regime;
II. Unloaded vehicle; and
III. Standard speed values of 100 and 120 km/h.

The results obtained in the 2 series of 4 measurements each are presented in *Table 2* below.

Table 2 Results of Dynamic Brake Testing (UIC 544-1)

Speed at the point of braking [km/h]	100				120			
Effective speed at the point of braking [km/h]	100.2	100.5	100.2	100.2	119.8	118.1	119.8	119.8
Measured braking distance [m]	369	359	347	365	519	534	526	526
Corrected value of braking distance (acc. annex F2.1 of UIC 544-1) [m]	367	356	346	364	521	550	528	528
Average braking distance [m]	358				532			
Braking distance (corrected average values, acc. annex F2.2 of UIC 544-1) [m]	**357**				**530**			

The ***braking distances*** were calculated using the average values of the measured distances, which were corrected according to Annex F2.2 of UIC 544-1.

The ***ratio of the braked weight*** can be calculated using the formula from Annex B of UIC Leaflet 544-1:

$$\lambda = \frac{C}{s} - D \qquad (2)$$

where:

λ ratio of braked weight, [%]
s braking distance, [m]
C, D standard coefficients (UIC 544-1)

The values in Equation 2 above and the computed values of the ratio of braked weight are given in *Table 3* below.

Table 3 Calculation of the ratio of braked weight (UIC 544-1)

Speed value at the point of braking [km/h]	100	120
Braking distance, s (corrected average values, acc. annex F2.2 of UIC 544-1) [m]	357	530
Coefficient C	52840	83634
Coefficient D	10	19
Ratio of braked weight, λ [%]	**138**	**139**

Finally, the computed values of the ratio of braked weight were corrected taking into account the ***dynamic efficiency of the brake linkage***, η_{dyn_t}, which was calculated as:

$$\eta_{dyn_t} = \frac{1+\eta_{stat_t}}{2} \tag{3}$$

using the values of static efficiency η_{stat_t} obtained in the static tests (see Section §3.1.1.1).

Considering the braked weight on shoes in tests, B_t, for brake shoes equipped with P10 blocks, and using the tables in Annex F or formulas in Section §2.2.2.1 of UIC Leaflet 544-1, the force in the tests, F_{dyn_t}, can be determined either directly or through linear interpolation.

The ***corrected value of the dynamic force on the brake shoes***, $F_{dyn_{corr}}$, can be calculated as:

$$F_{dyn_{corr}} = F_{dyn_t}\frac{0.83}{\eta_{dyn_t}} \tag{4}$$

From this corrected value of the dynamic force, the corrected value of the braked weight on shoes, B_{corr}, can be determined from the same tables in Annex F (or using the formulas in Section §2.2.2.1).

Using the corrected braked weight, the ***corrected ratio of the braked weight*** can be determined:

$$\lambda_{corr} = \frac{B_{corr}}{\text{wagon tare}} \tag{5}$$

The tare weight of the tested wagon was 21.6 t, so the final values of the corrected ratio of braked weight are:

$\lambda_{corr} = 124\%$ at 100 km/h;
$\lambda_{corr} = 125\%$ at 120 km/h.

The ratio of braked weight values determined above fall within the upper limit recommended for the test conditions (P regime, unloaded), respectively 105 – 125 %, according to UIC 544-1 and SR 12300/98.

3.1.2 Noise Level Measurements

The tests for the measurement of the noise level were carried out on the test track at AFER's Testing Centre at Faurei (*Figure 6*). An experimental rake configuration was used to measure the noise emitted by the tested wagon. The rake consisted of an electric locomotive, a laboratory wagon (to separate the noise produced by the locomotive), and the tested wagon at the end.



Figure 6 Location of experimental set up for noise level measurements on the test track

The experimental set up was made according to the requirements of national standard STAS 6661-82, which is superseded by EN ISO 3095:2005. The main difference between the new and the old versions of this regulation, with respect to the tests which were carried out, consists in the positioning of the microphones for measuring the sound (i.e., different distances to the track and height, see *Figure 7*).

The tests consisted of the measurement of the noise emitted by the tested vehicle when running on the test track, at constant speeds of 100 and 120 km/h. The microphone axis was horizontally positioned and directed perpendicularly to the track. The microphone was installed in the location marked 2 in *Figure 6*, in the standard microphone position shown in *Figure 7*. It was positioned to the side of the track, at a distance of 30 m from the track axis, and at a height of 2.5 m ± 0.2 m above the top of the rail.

According to the standard requirements, the level of the background noise should be limited during the tests. Thus, the standard requires that the tests should be performed when the wind speed is below 5 m/s. Unfortunately, this condition related to the wind speed could not be met, as the wind speed was significant higher than the recommended limit on the day when the tests were planned and carried out. For this reason, a series of measurements of the level of background sound were performed, to allow the separation of this noise from the noise emitted by the tested wagon (*Figure 9* and *Figure 10*).

The measurements were made using an integrating logging sound level meter type Rion NL-32 (*Figure 8*). Three sets of measurements were made for each speed. Taking into account the significant and variable level of the background noise, two measurements were made for each of the three sets corresponding to each the two wagon speeds, respectively:

- An initial measurement of the background noise, when the front of the train reaches location 1 in *Figure 6*, a few seconds before the actual measurement;
- The measurement of the noise emitted by the tested wagon at constant speed when passing by location 2; measurement procedure (start/end, scale, etc.) according to standard.

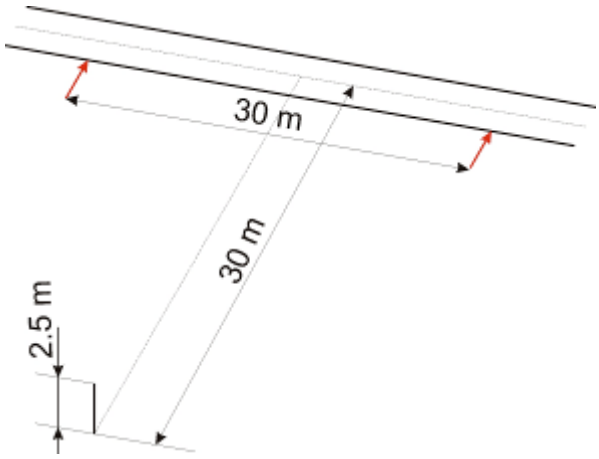


Figure 7 Experimental set up (positioning of equipment for noise level measurements - standard STAS 6661-82, superseded by EN ISO 3095:2005)

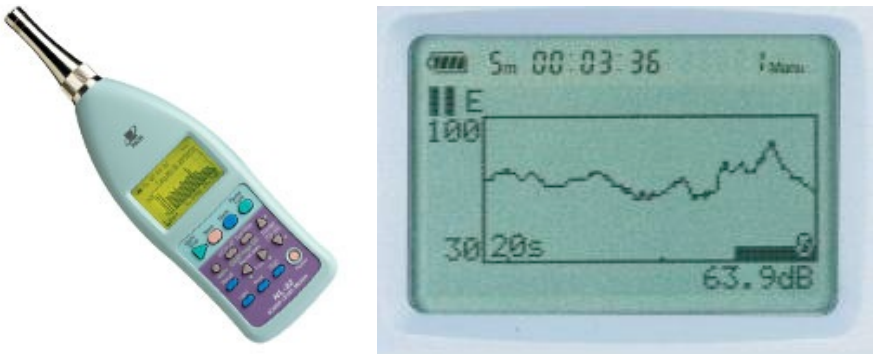
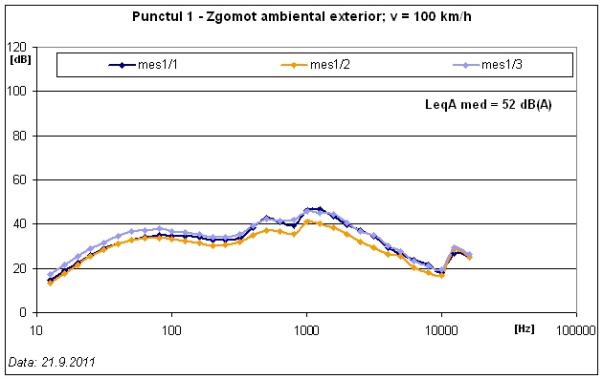


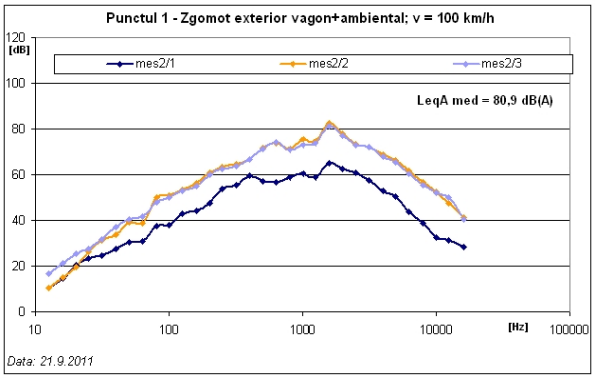
Figure 8 Sound level meter Rion NL-32 used for noise level measurements

Both locations (1 and 2 in *Figure 6*) were selected on a straight line, without any elements which could have influenced the noise level (both infrastructure elements such as crossings, switches, bridges, etc., and natural ones, such as trees, slopes, etc., were considered).

Following the above procedure, 2 sets of 6 measurements each (3 for background noise and 3 for the wagon noise) were recorded, and are presented in *Figure 9* and *Figure 10*.

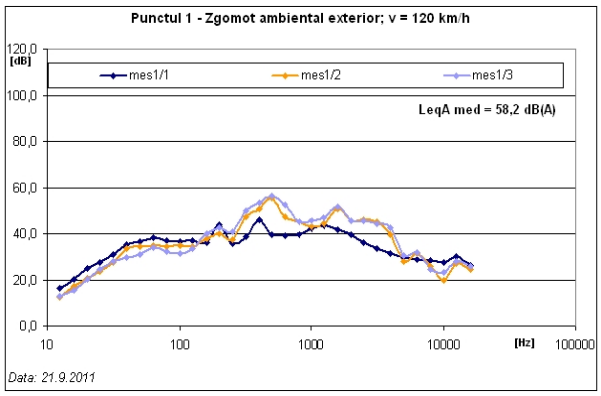


a) Level of environmental noise

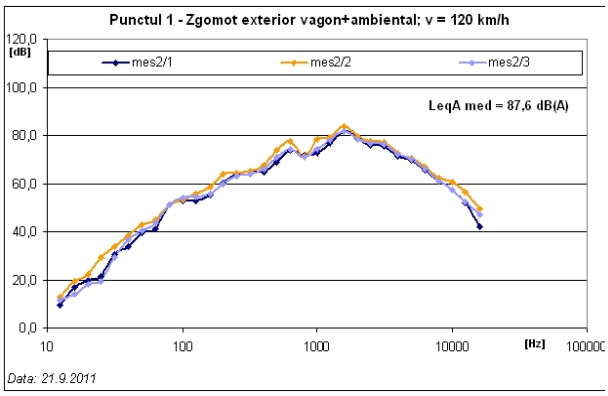


b) Level of noise on vehicle with constant speed

Figure 9 Measurements of noise level on vehicle with constant speed of 100 km/h



a) Level of environmental noise



b) Level of noise on vehicle with constant speed

Figure 10 Measurements of noise level on vehicle with constant speed of 120 km/h

3.1.3 Wheel Profile Measurements

The wheel profiles of the test vehicle were measured with a MiniProf standard wheel profile measuring device, shown in *Figure 11*. This device has a main body which is clamped firmly to the wheel by a magnetic bracket; the design of the bracket ensures accurate and repeatable location of the main body of the device relative to the wheel profile. The profile measurements are taken with an arm made of two linked segments, one segment is attached to the main body of the device at one end and the other segment is attached to the other end of the first segment; these joints only permit rotation of the arms about an axis normal to a plane which is parallel to, and includes, the central axis of the wheel-set. The joints are fitted with rotary encoders which measure the angles of the first and second segments in relation to the body and first segment respectively. At the extreme end of the arm is a small magnetic measurement wheel, which is of significantly smaller radius than any part of a standard wheel profile, and this rotates in the measurement plane.



Figure 11 MiniProf standard wheel profile measuring device fitted to a wheel in position to make a measurement

To make a measurement, the measurement wheel is drawn across the wheel profile (without the rest of the arm coming into contact with the wheel); the measurement wheel must remain in contact with the wheel throughout for the measurement to be valid. From the angles measured by the rotary encoders and the known dimensions of the arm, a series of coordinates for the point of contact between the measurement wheel and wheel are calculated, giving the profile of the wheel. The MiniProf Wheel unit has a stated accuracy of better than ±36 µm and the repeatability of the measurements is stated as ±20 µm. To ensure accurate measurement of the profile, the track that the measurement wheel is to traverse, and the points where the body supporting bracket make contact with the wheel, must be cleaned of any wear debris or contaminants, such as grease, crushed ballast or dirt, before attaching the MiniProf. For the testing program described here, one profile measurement was made on each wheel of the test vehicle along a measurement path which was visually assessed to be representative of the wheel, this measurement procedure was carried out on the test vehicle both before and after the dynamic brake testing described in Section §3.1.1. Also, during the measurement procedure, additional wheel profile measurements were taken which had measurement paths (that is, the line which the measurement wheel of the MiniProf travels during measurement) that crossed selected discrete features on the wheels that were visible, such as flat areas on the circumference of the wheel caused by the wheel sliding along the rail during braking.

3.1.3.1 Analysis of Wheel Profile Measurements

The software provided with the MiniProf devices has been used to analyse the data points collected for each wheel profile, particularly the comparison of the measured profiles with a reference profile. The reference profile is the target or design profile of the wheels to which the wheels are manufactured and maintained. There are a number of standard wheel profile designs in use, but the design profile for the wheels on the test vehicle is the S78 profile[2]. At manufacture there will have been some deviation of the wheel profiles from the reference profile, depending on the manufacturing tolerance. As the vehicle travels in service, the surface of the wheel will be worn away at different rates from different portions of the profile, altering the profile. At intervals the wheels are re-profiled using a lathe to maintain the wheel profile within set tolerances of the reference profile. When there is insufficient material remaining on the outer part of the wheel for it to be re-profiled to a profile within specification, the wheels are removed from service.

The wheel-sets on the test vehicle had been in use for a significant period of time but had recently been re-profiled; the only use the vehicle had between the re-profiling of the wheels and the tests was during the transit of the vehicle from the maintenance facility to the test site.

The first stage of analysing the wheel profile measurements was to align each one with the reference profile; the alignment criteria used was that the profiles should intersect at two points. The first point of intersection was where the tangent of the outside of the flange is at 45º to the axis of the axle, the second point of intersection was on the outer end of the wheel tread, 10 mm from the outer end of the reference profile.

After the alignment of the measured profile with the reference profile, a series of calculations were performed using the software. The ***Wheel Wear*** parameter makes measurements of the profile at specific locations; this calculation was also performed on the reference profile for comparison. The other calculations calculate the difference between the measured profile and the reference profile, so that the deviation of the reference profile can be quantified according to set criteria which allow specific limits to be set for the amount of deviation of a profile from the reference. The calculations performed to obtain the values of the ***Wheel Wear***, ***Residuals***, ***Wheel Wear Difference*** and ***Wheel Hollowing*** parameters are described below and the values for each measured profile are shown in *Table 4*.

The ***Wheel Wear*** parameter consists of three measurements taken at specific locations on the profile, shown in *Figure 12*. The Sd measurement gives the thickness of the flange at the transition between the flange face and the radius between the flange face and the wheel tread; this point is determined by the dimensions L2 and L3, L2 being the distance from the flange back to the centre of the wheel tread, and L3 is the radial distance from the point on the wheel tread defined by L2.

The Sh measurement gives the maximum height of the flange above the point on the wheel tread defined by L2. The qR measurement gives the distance along the axis of the axle between the point on the flange face used in the Sd measurement and another point on the flange face as specified distance below the maximum height of the flange, this distance being L1. The values of L1, L2 and L3 used in to obtain the profile measurements in *Table 4* were 2 mm, 70 mm and 10 mm respectively.

[2] Unfortunately, we were unable to obtain an official MiniProf reference file for the Romanian S78 wheel profile, but were able to get two mathematical descriptions of the profile. These were used to create a reference file, and this is given in Appendix 3.

Table 4 Wheel profile parameters – measurements and calculations

Vehicle	Wheel	Axle	Measure-ment ID	Condition	Wheel Wear			Residuals			Wheel Wear Difference			Wheel Hollowing	
					Sd	Sh	qR	Min	Max	Av.	dSd	dSh	dqR	H	X
N/A	Ref S78	N/A		Ref	32.500	28.000	10.794								
T	1	1	General	Pre-Test	29.837	28.374	9.822	-0.495	2.347	0.387	-2.663	0.374	-0.971	0.000	70.222
T	2	2	General	Pre-Test	29.706	27.964	8.917	-0.055	2.639	0.519	-2.794	-0.036	-1.876	0.000	70.103
T	3	3	General	Pre-test	31.328	27.861	10.314	-0.155	1.395	0.567	-1.172	-0.139	-0.480	0.000	70.057
T	4	4	General	Pre-test	29.245	27.872	9.498	-0.076	2.984	0.701	-3.254	-0.128	-1.295	0.000	70.099
T	5	1	General	Pre-test	30.958	28.086	10.511	-0.070	1.617	0.387	-1.542	0.087	-0.283	0.000	70.140
T	5	1	AcPit	Pre-test	30.687	27.871	10.415	-0.068	1.894	0.513	-1.813	-0.128	-0.378	0.000	70.233
T	6	2	General	Pre-test	29.558	27.976	8.875	-0.081	2.716	0.593	-2.942	-0.024	-1.919	0.000	70.194
T	7	3	General	Pre-test	32.727	28.431	10.385	-1.041	0.302	-0.346	0.227	0.432	-0.409	0.000	70.207
T	8	4	General	Pre-test	30.540	28.024	10.284	-0.864	2.056	0.003	-1.960	0.025	-0.509	0.000	70.248
T	4	4	General	Post-test	29.356	27.879	9.470	-0.065	0.938	0.660	-3.144	-0.120	-1.323	0.000	70.051
T	4	4	AcWF	Post-test	30.146	28.485	9.634	-0.418	2.221	0.361	-2.354	0.485	-1.160	0.000	70.195
T	4	4	AcWF-2	Post-test	30.166	28.287	9.528	-0.585	2.045	0.192	2.333	0.287	-1.266	0.000	70.167
T	3	3	General	Post-test	32.375	28.354	10.470	-0.333	0.136	0.061	-0.125	0.354	-0.324	0.000	70.056
T	3	3	AcWF	Post-test	32.503	28.675	10.694	-0.274	0.448	0.165	0.003	0.676	-0.099	0.000	70.038
T	2	2	General	Post-test	28.786	27.543	8.759	-0.320	3.632	0.953	-3.714	-0.457	-2.035	0.000	70.150
T	1	1	General	Post-test	29.586	28.288	9.832	-0.295	2.668	0.562	-2.913	0.289	-0.962	0.000	70.183
T	5	1	General	Post-test	30.893	27.982	10.477	-0.030	1.680	0.396	-1.607	-0.017	-0.317	0.000	70.069
T	6	2	General	Post-test	29.854	28.107	8.882	-0.136	2.402	0.432	-2.646	0.108	-1.911	0.000	70.096
T	7	3	General	Post-test	32.198	27.963	9.830	-0.417	0.843	-0.014	-0.302	-0.036	-0.964	0.000	70.085
T	8	4	General	Post-test	30.719	28.100	10.310	-0.913	1.883	-0.071	-1.781	0.100	-0.484	0.000	70.024
T	8	4	AcWF	Post-test	30.758	28.383	10.461	-0.725	2.099	0.123	-1.742	0.384	-0.333	0.000	70.242
S	1	1	General 1	End of life	29.872	29.606	7.544	-0.819	2.950	1.085	-2.628	1.606	-3.249	-0.015	70.445
S	1	1	General 2	End of life	29.517	29.624	7.669	-0.473	3.307	1.198	-2.983	1.624	-3.125	0.000	70.073
S	2	2	General 1	End of life	31.504	29.383	10.654	-0.219	2.770	1.534	-0.996	1.384	-0.140	-0.629	83.724
S	2	2	General 2	End of life	31.461	29.385	10.457	-0.243	2.820	1.559	-1.039	1.385	-0.336	-0.637	84.095

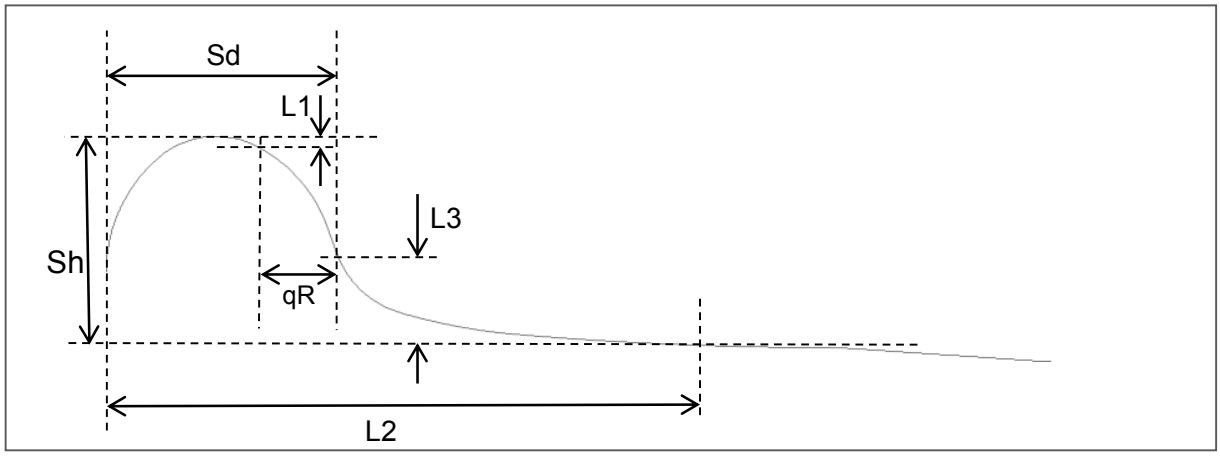


Figure 12 Dimensions defining measurement of the ***Wheel Wear*** parameter

The ***Residuals*** are the values of the measured difference between the measured profile and reference profile. Each measurement is made in a direction perpendicular to the tangent of the reference profile at that point. For each of the measured profiles, the maximum and minimum residual values, as well as the average of all the residual values, have been calculated. The sections of the profile less than 1 mm from the flange back and less than 10 mm from the outside end of the profile were excluded from the calculations.

The ***Wheel Wear Difference*** values dSd, dSh and dqR are obtained by subtracting the respective ***Wheel Wear*** measurements of Sd, Sh and qR for the reference profile from the equivalent measurements taken from the measured profile. These values give an indication of the extent to which the measurement profile deviates from the reference profile, particularly with regard to the profile of the flange.

The ***Wheel Hollowing*** value calculates the maximum distance between the tread of the reference profile and the tread of the measured profile (H), and also the distance from the back of the flange (X) at which this occurs. The wheel hollowing measurements are represented in *Figure 13*, where they are superimposed on plots of the measured profile of a severely worn wheel of a vehicle scheduled to be scraped (not the test vehicle) and the reference profile. Whilst the profiles plotted in *Figure 13* are to scale, the dimension lines are just for illustrative purposes and don't represent the actual location of maximum hollowing on the measured profile. The values of the angle A between the wheel tread and the normal of the measurement direction used for the values presented in *Table 4* is 0º.

The values of the parameters calculated for each measured profile, and where appropriate for the reference profile, are shown in *Table 4*. The vehicle column denotes whether the measurement was taken from the test vehicle (denoted by a T) or a similar vehicle scheduled to be scraped (denoted by an S). The measurement ID column denotes whether the wheel profile measurement was along a path that was visually judged to be representative of the whole wheel (classified as General, with a numerical suffix if more than one measurement were taken), or if it was an additional measurement which included selected discrete features on the surface of the wheel. The additional measurements are classified as AcPit and AcWF where the discrete feature included in the profile measurement was a pit in the surface of the wheel or a wheel flat respectively, with a numerical suffix if more than one measurement of each classification were taken.

Selected examples of the measured profile, plotted and aligned alongside the S78 reference profile, are shown in *Figure 14* to *Figure 16*.

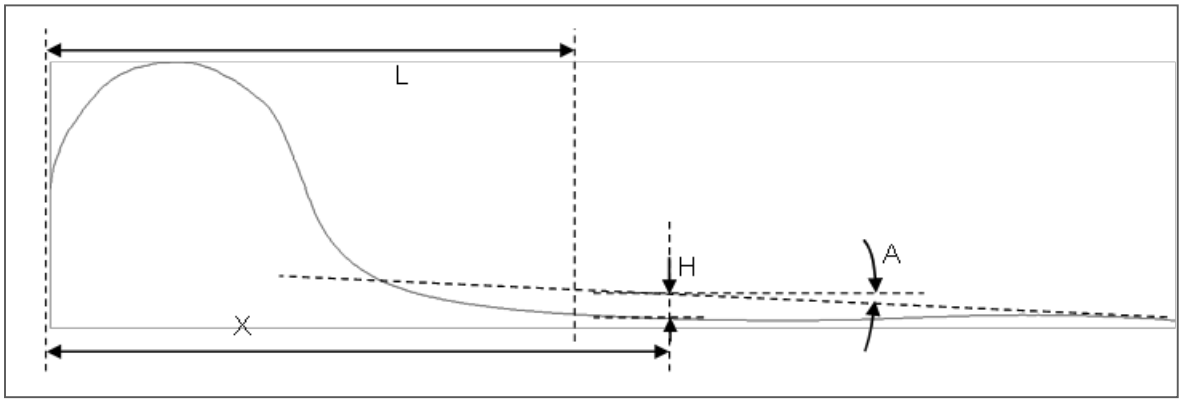


Figure 13 Scale plot example indicating the dimensions used to calculate the Wheel Hollowing parameter

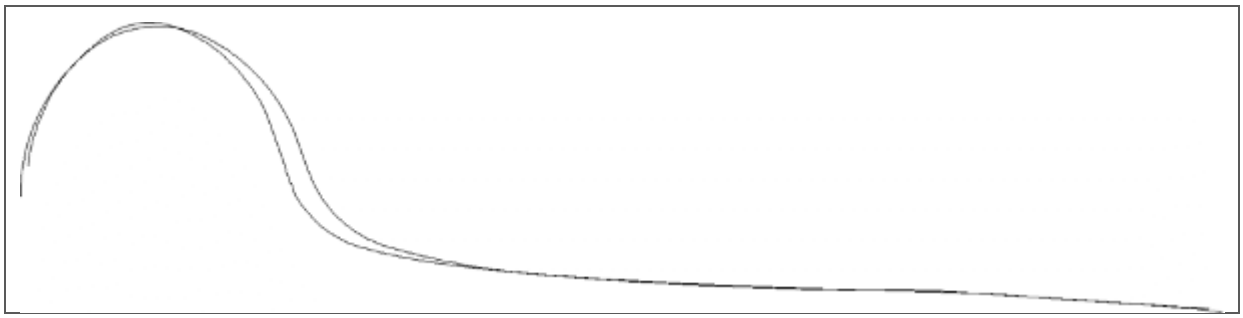


Figure 14 Example of wheel profile measurement plotted against the S78 reference profile (wheel 1 of the test vehicle measured before the dynamic brake testing)

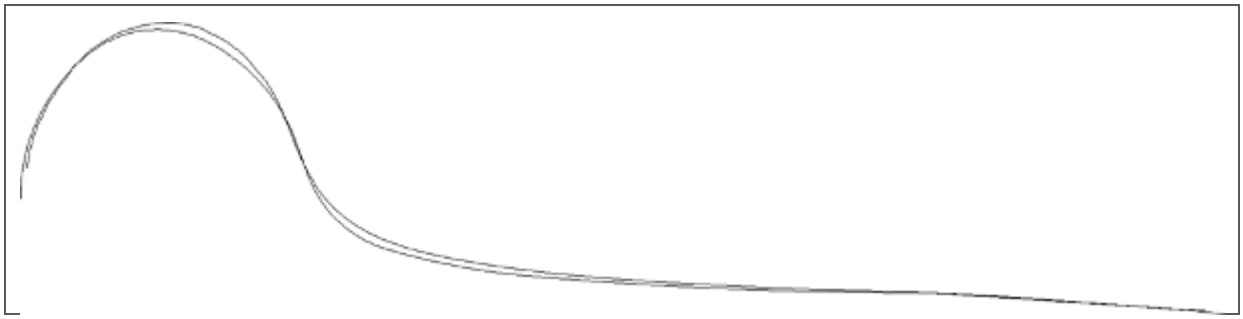


Figure 15 Example of wheel profile measurement plotted against the S78 reference profile (wheel 7 of the test vehicle measured before the dynamic brake testing)

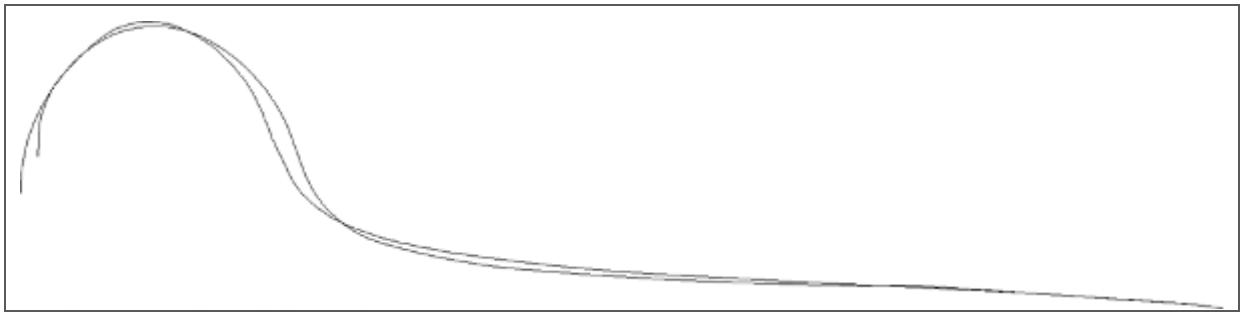


Figure 16 Example of wheel profile measurement plotted against the S78 reference profile (wheel 8 of the test vehicle measured before the dynamic brake testing)

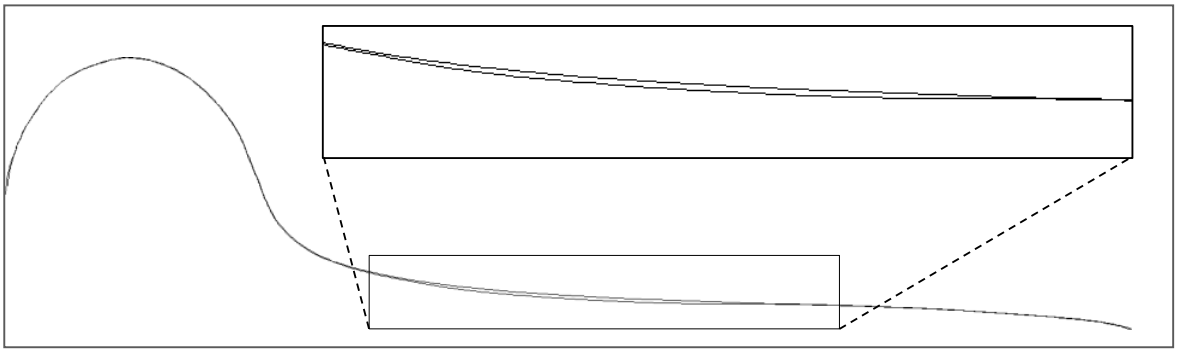


Figure 17 Example of two profiles plotted together (wheel 3 of the test vehicle after the dynamic brake testing)

In *Figure 17*, two profiles measured from wheel 3 of the test vehicle after the dynamic brake testing have been aligned with each other and are plotted together with an enlargement of the profiles at the centre section of the tread. The profile which is uppermost at the centre section of the tread was measured at a section of the wheel visually judged to be representative of the majority of the wheel surface, while the lower profile was measured across a wheel flat.

The plots and calculated values show that the wheels on the test vehicle had flanges which were generally thinner than the reference profile, and that the geometry of the wheel profile across the tread was a close match with the reference profile, showing no signs of wheel hollowing as shown by the heavily worn wheels on the vehicle due to be scrapped. These measurements from the test vehicle are consistent with the wheel-sets having been used in traffic for a period of time, hence losing some of the material from the thickness of the flange, and then recently being re-profiled. The wear that has taken place on the wheel profile prevents the re-profiling from producing a wheel profile with the as-manufactured flange thickness, but there was sufficient material remaining in the tread for any hollowing to be removed by turning down the radius of the outer portion of the tread to re-instate the conical profile to the tread.

The wheel flats observed on the treads of the wheels were most likely caused by the wheel-sets stopping rotating whilst the vehicle was still moving, due to the application of more braking force to the wheels than there was adhesion at the wheel-rail contact to enable the wheels to keep rolling; this most likely occurred during the severe brake applications of the dynamic brake testing. The wheels flats observed appeared as a circular patch approximately 10-20 mm in diameter, located approximately on the centre of the tread. The flats exhibited different reflective properties to the rest of the wheel; an example from wheel 4 is shown in *Figure 18*. The Sh ***Wheel Wear*** parameter values (which is the difference in height between the top of the flange and the centre of the wheel tread) for the profiles taken across the wheel flat, were greater by between 0.284 mm and 0.660 mm than those for the profile taken on a representative section of the same wheel after the dynamic brake testing. This could be interpreted as indicating the amount of material removed from the profile (measured radially) by the sliding action that caused the wheel flat; however, it should be noted that whilst the Sh measurement for wheels 4 and 8 after the dynamic brake testing were within 0.08 mm of each other, the same measurements for wheel 3 showed a change of 0.493 mm indicating an inconsistency in the wheel profile around the circumference or in the measurement of the profiles. It is unlikely that the rolling contact and the contact of the brake shoes during the dynamic brake testing would have removed the amount of material to produce this indicated change in radius around the whole wheel. The pit in the tread of wheel 5, across which an additional measurement was made, was probably caused by a foreign object, such as a piece of ballast stone, for example, getting into the wheel-rail contact.



Figure 18 Wheel flat after the dynamic brake testing (the wheel flat is in the lower right quarter of the picture, the flange is towards the top left)

3.2 Infrastructure Measurements on the Test Track

3.2.1 Track Measurements

The track was measured and checked against the design specifications on key selected locations of the testing centre. The ***gauge*** and ***the cant of the track*** were measured according to the procedure stated in national CFR 314 Leaflet (Requirements and tolerances for track building and maintenance: Normal track gauge). The measurements were made with a *Track Gauge and Superelevation Measuring Device type ROBEL, series 655*. The gauge and cant were measured above the sleepers (between 7-30 measurements) in the following ***three locations*** on the high speed test track:

a. through the switch no. 10 (km 0+340, *Figure 19* and *Figure 20*);
b. on the main straight line, along the platform in front of the functional buildings (km 0+424);
c. on a curved section (radius 1800 m) of track which crosses a small concrete under-bridge (km 12970+30, *Figure 21*).

The measurement results are presented in *Table 5* - *Table 7* below.

Table 5 Track gauge and cant measurements on section a. (km 0+340)

Sleeper no.	**Track gauge deviation (E=1435 $^{+1}_{-1}$ [mm])**	**Cant (NT $^{+5}_{-5}$ [mm])**
1	+1	+3
2	0	0
3	+1	+2
4	+1	+2
5	+1	+2
6	+1	+1
7	-1	+2

Table 6 Track gauge and cant measurements on section b. (km 0+424)

Sleeper no.	**Track gauge deviation (E=1435 $^{+1}_{-1}$ [mm])**	**Cant deviation (NT $^{+5}_{-5}$ [mm])**	**Sleeper no.**	**Track gauge deviation (E=1435 $^{+1}_{-1}$ [mm])**	**Cant deviation (NT $^{+5}_{-5}$ [mm])**
1	-1	+3	31	0	+1
2	-1	+3	32	0	+1
3	-1	+3	33	0	+1
4	-1	+3	34	0	+1
5	-1	+3	35	0	+1
6	-1	+3	36	0	+2
7	-1	+3	37	0	+2
8	-1	+4	38	-1	+2
9	-1	+4	39	-1	+2
10	-1	+3	40	-1	+2
11	-1	+3	41	-1	+2
12	-1	+3	42	-1	+3
13	-1	+3	43	-1	+3
14	-1	+3	44	-1	+3
15	-1	+3	45	-1	+3
16	-1	+3	46	-1	+3
17	-1	+3	47	-1	+3
18	-1	+3	48	-1	+3
19	-1	+3	49	-1	+3
20	-1	+3	50	-1	+3
21	-1	+3	51	-1	+3
22	0	+3	52	-1	+3
23	0	+3	53	-1	+3
24	0	+2	54	0	+3
25	0	+2	55	0	+3
26	0	+2	56	0	+3
27	0	+2	57	0	+2
28	0	+2	58	0	+2
29	0	+2	59	0	+2
30	0	+2	60	0	+2

Table 7 Track gauge and cant measurements on section c. (km 12.970+30)

Sleeper no.	**Track gauge deviation (E=1435 $^{+1}_{-1}$ [mm])**	**Cant (NT $^{+5}_{-5}$ [mm])**	**Sleeper no.**	**Track gauge deviation (E=1435 $^{+1}_{-1}$ [mm])**	**Cant (NT $^{+5}_{-5}$ [mm])**
1	0	143	26	0	143
2	0	143	27	0	143
3	0	143	28	0	143
4	0	143	29	0	145
5	0	143	30	0	145
6	0	143	31	0	145
7	0	143	32	0	145
8	-1	143	33	0	145
9	-1	143	34	0	145
10	-1	143	35	0	145
11	0	143	36	0	145
12	0	143	37	0	145
13	0	143	38	0	145
14	+1	143	39	0	145
15	+1	143	40	0	145
16	+1	143	41	0	145
17	+2	143	42	0	145
18	+2	142	43	0	145
19	+1	142	44	0	145
20	0	142	45	+1	145
21	0	142	46	+1	145
22	-1	142	47	+1	145
23	-1	143	48	+1	145
24	-1	143	49	+1	145
25	0	143	50	+1	145

3.2.2 Track Profile Measurements

Measurements of the rail profile at various locations around the test track were taken using a MiniProf Rail device (*Figure 11*). Both the version of the device, and the measurement method used, meant that not only was the profile of the rail measured accurately, but that track gauge and rail angle (inclination) were automatically measured also. Several measurements were taken around the test track at different locations, the locations being selected so as to give a sample of measurements from locations around high speed circuit of the test track which were of different characteristic types. The same measurements were taken from both rails at each location and saved for later analysis. The MiniProf Rail device used is similar to the MiniProf Wheel device described in Section §3.1.3, both devices having a main body attached to which is a measurement arm of two segments with rotary encoders at the joints and a magnetic wheel at the end which traverses the profile to take a measurement. The MiniProf Rail device differs in that it is magnetically attached to the top of the rail head; it is aligned manually so that the plane which the precision bearings constrain the measurement wheel to move in is normal to the longitudinal axis of the rail. An optional additional rod which attaches to the side of the main body and rests on the opposite rail was used. This rod is of known length and has a reference point which makes contact with the gauge point on the opposite rail; this allows the track gauge to be calculated from the profile measurement. The MiniProf Rail has a stated accuracy of better than ±54 μm and the repeatability of the measurements is stated as ±20 μm. As with the wheel profile measurements, the contact locations of the device, and the path which the measurement wheel takes across the rail, must be clean and free of loose debris and contaminants for the profile to be measured accurately.

3.2.2.1 Measurement Locations

The rail on which a the profile was measured at each location is identified as either the high or low rail; this is applied to both curved and tangent track, as the test track only curves one way with respect to the direction of travel. Therefore, the high rail is always the outer rail of the test track circuit.

Locations on the high speed test track circuit where rail profile measurements were taken where:

- 6 locations through a set of switches and crossing (*Figure 19* and *Figure 20*);
- Three locations 20 m apart on a 1800 m radius curve;
- Three locations 20 m apart on a tangent section of track;
- Three locations on a curved section of track which crosses a small concrete under-bridge; one measurement location was on the centre of the bridge, and one 20 m each either side of the centre (*Figure 21*). The track at this location has a curvature of 1800 m radius. *Figure 21* shows the bridge and the relationship between it and measurement locations 6 and 7; measurement location 8 is not visible in *Figure 21*, but is a similar distance to the left of the bridge in that view as measurement location 6 is to the right of the bridge.

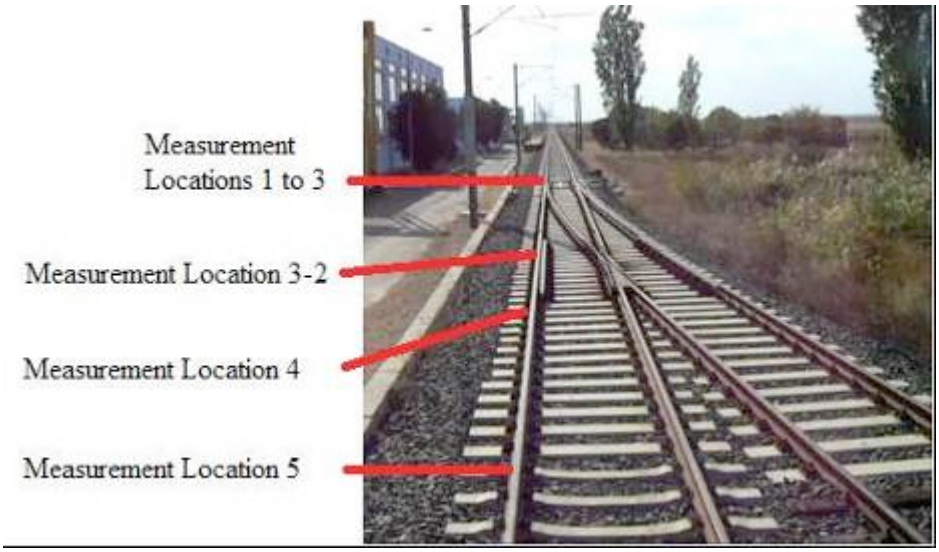


Figure 19 Test track with the *'Switch and Crossing'* measurement locations 1 to 5

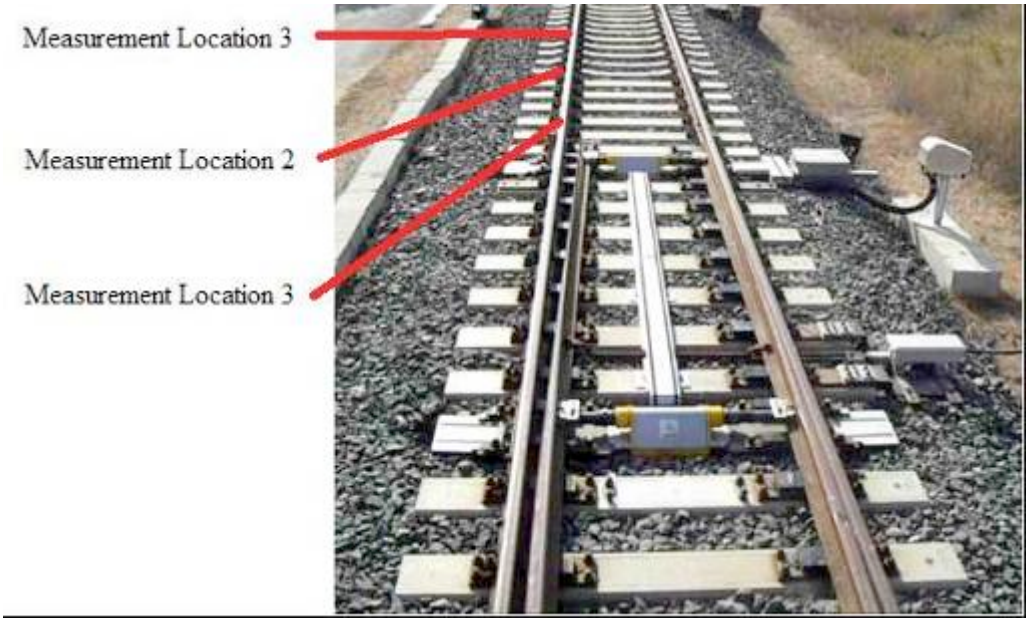


Figure 20 Close up view of part of the *'Switch and Crossing'* measurement location, showing measurement locations 1 to 3



Figure 21 Small concrete bridge associated with measurement locations 6-8 (locations 6, 7 labelled

3.2.2.2 Rail profile measurement results

The saved rail profile measurements taken from both rails at the measurement locations were each compared to a reference profile for UIC60 rail track, which is the type of rail used on the high-speed circuit of the test track, software provided with the MiniProf device. For each profile measured, the amount of wear was calculated as the difference between the measured profile and the reference profile at three standard points around the profile. The results of these wear calculations and the other measurements taken with the MiniProf at each location are shown in *Table 8*.

Table 8 Results of rail track profile measurements

Measurement Location	Type of Location	Rail	Wear values, [mm]				Gauge [mm]	Rail Angle
			W1	W2 L =12mm	W3 @ 45deg	W3 @ 60deg		
O1	S&C	High	0.347	-0.173	0.207	0.005	1435.50	1.56
I1	S&C	Low	0.064	-0.074	0.027	-0.024	1434.90	2.23
O2	S&C	High	0.414	-0.171	0.264	0.013	1436.50	1.04
I2	S&C	Low	0.093	-0.173	0.063	-0.063	1436.30	1.66
O3	S&C	High	0.505	0.138	0.427	0.068	1436.50	-0.54
I3	S&C	Low	0.025	0.098	0.144	-0.05	1437.00	-0.10
O3-2	S&C	High	-0.024	0.056	0.139	0.059	1435.02	-0.87
I3-2	S&C	Low	0.025	0.212	0.474	0.357	1437.06	-1.15
O4	S&C	High	0.413	-0.163	0.279	0.055	1441.00	-1.23
I4	S&C	Low	0.149	0.005	0.119	-0.075	1436.29	-0.26
O5	S&C	High	0.369	-0.131	0.206	0.015	1438.78	0.91
I5	S&C	Low	0.170	-0.100	0.257	0.049	1438.39	1.50
O5-4	Tangent	High	0.363	-0.03	0.235	0.092	1437.74	1.87
I5-4	Tangent	Low	0.576	-0.265	0.211	0.020	1437.22	1.83
O5-5	Tangent	High	0.517	0.035	0.313	0.159	1436.53	2.08
I5-5	Tangent	Low	0.659	-0.160	0.273	0.059	1436.53	1.92
O5-6	Tangent	High	0.557	-0.119	0.288	0.086	1436.18	2.00
I5-6	Tangent	Low	0.297	-0.157	0.277	0.067	1435.84	1.62
O5-7	Curve	High	0.372	0.093	0.482	0.314	1436.35	1.85
I5-7	Curve	Low	0.557	-0.194	0.221	0.023	1435.37	2.07
O5-8	Curve	High	0.554	-0.185	0.247	0.010	1437.46	1.97
I5-8	Curve	Low	0.425	0.026	0.403	0.213	1437.27	1.97
O5-9	Curve	High	0.672	-0.029	0.433	0.209	1437.21	1.82
I5-9	Curve	Low	0.635	-0.202	0.203	-0.039	1437.82	1.67
O6	Bridge	High	0.338	0.199	0.539	0.387	1436.54	1.90
I6	Bridge	Low	0.542	0.042	0.484	0.270	1437.04	1.34
O7	Bridge	High	0.391	0.18	0.546	0.394	1436.22	1.97
I7	Bridge	Low	0.711	-0.029	0.406	0.202	1434.40	1.86
O8	Bridge	High	0.495	0.099	0.488	0.315	1436.17	2.21
I8	Bridge	Low	0.676	0.081	0.331	0.124	1437.17	1.74

The results in *Table 8* show that little material has been worn from the rails, the amount of wear ranging from 0.025-0.711 mm for the vertical wear at centre of rail head (W1); this is compared to wear limit of around 14 mm at the centre of the rail level for a main line. The results also show that very little material has been worn from the gauge side of the rail profile (W2), and that the wear on the gauge corner of the rails was generally somewhere between that at the centre of the rail and that at the gauge side. There is no obvious pattern to the amount of wear; for example, it was *not* observed that more material was worn from the rails at locations where the track is curved. However, this may be because the amount of wear is too low for wear patterns to be evident above random variation in the wear measurements.

Example profiles are plotted in *Figure 22* and *Figure 23*, which show the rail profiles taken at measurement locations I2 (file6) and I7 (file19) respectively. Each profile is shown with the reference profile for UIC60 rail, with the gauge face on the right hand side of each image. Location I2 was chosen to provide illustrative examples as it was among the locations which had the lowest amount of wear at the centre of the rail; similarly location I7 was chosen as it was among the locations which had the highest amount of wear. This can be seen from the fact that in *Figure 22* the measured profile from location I2 is indistinguishable from the reference profile at the scale the profiles are plotted at, whereas in *Figure 23* there is a small but discernible difference between the profile measured at location I7 (the lower line) and the reference profile.

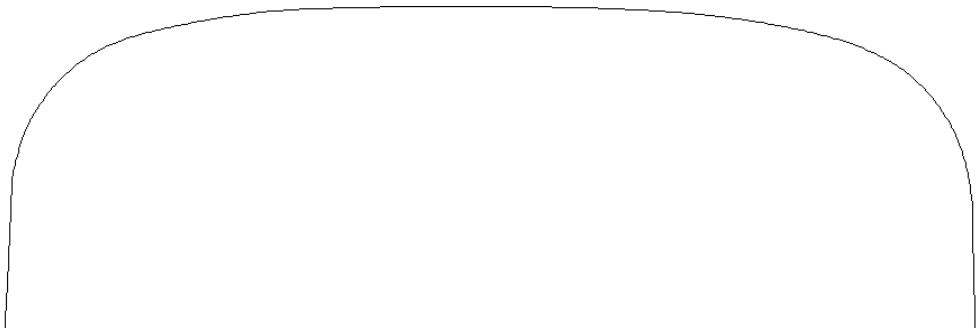


Figure 22 Plot of the UIC60 reference profile and the profile measured at location I2

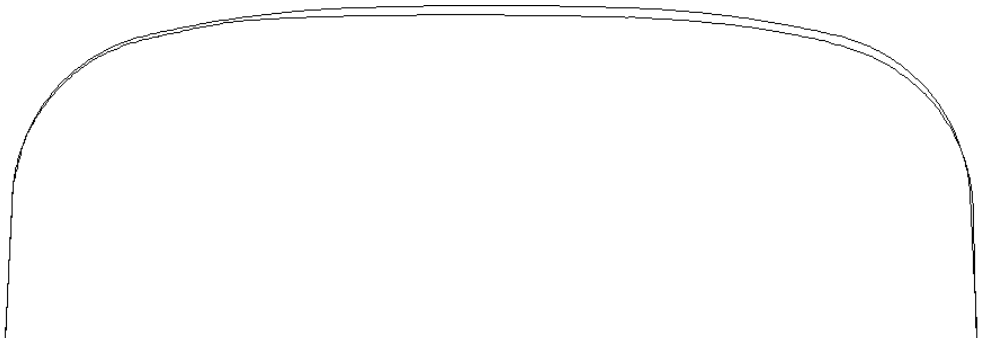


Figure 23 Plot of the UIC60 reference profile (upper line) and the profile measured at location I7 (lower line)

3.3 Other Testing Possibilities

Apart the tests regularly carried out by AFER, the SUSTRAIL partners MERMEC and TRAIN have proposed to extend the vehicle-track system testing using technologies which they will provide for further testing activities (on the selected type of vehicle and the final SUSTRAIL prototype).

3.3.1 Tests proposed by MERMEC

The MER MEC Diagnostic Products proposed for SUSTRAIL testing activities belong to two main categories:

- On-board measurement systems
- Wayside measurement systems

The following systems are proposed for measuring and testing the vehicle parameters and related characteristics:

- On board measurement systems
  - ✓ Ride Quality Measurement System
  - ✓ Rail Profile Measurement System
  - ✓ V-cube
- Wayside measurement systems
  - ✓ Wheel Surface Defects
  - ✓ Thermal Inspection System

The proposed systems are briefly presented below.

MER MEC Group Ride Quality Measurement System is able to measure the accelerations on each suspension level (axle box, bogie frame and vehicle coach) in order to provide information regarding the running dynamics at very high speeds (up to 320 km/h). The following table shows the parameters which could be measured using this system.

Table 9 Ride Quality parameters

Parameter
Vertical and Transversal accelerations on axle boxes, bogie and vehicle body
Standard Deviation of the vertical and transversal accelerations measured on the bogie and on the vehicle body
RMS of the measured accelerations
Quasi stationary value of transversal accelerations measured on the vehicle body frame (F_0)
F_1, F_2 values concerning all the measured accelerations

The Ride Quality system uses accelerometers which are installed as shown in *Figure 24*.

The analysis of the parameters measured with the Ride Quality system provides information on:

- Travelling Comfort
- Safety Conditions of the Track

The system requires a rack installed on board in order to contain the PC used for acquisition and processing which provides, as output, the defects report. The Power Supply for the Ride Quality Measurement System is about 200 W.

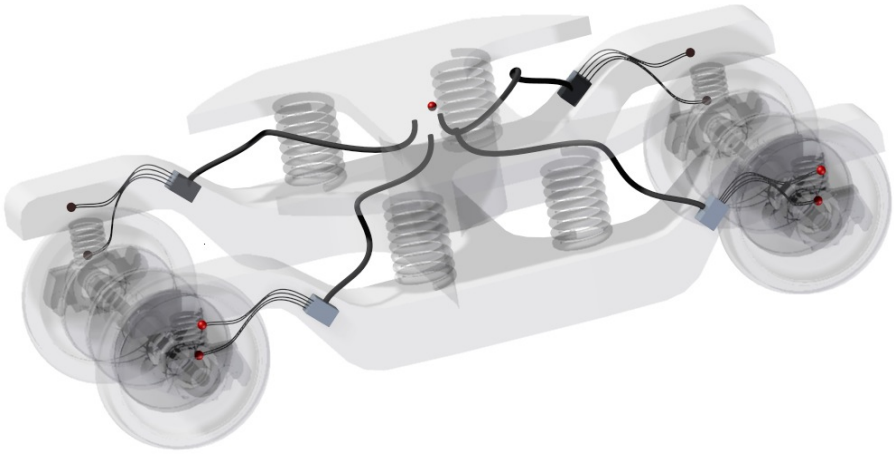


Figure 24 Example of Ride Quality accelerometers set up

MER MEC Group Rail Profile Measurement System (*Figure 25*) is able to check the entire rail profile and provide measurements regarding rail wear (horizontal, vertical, at 45°, head loss, gauge and field lip, etc.

The technologies which MER MEC implements in this product are optical-chord based or opto-inertial, and can be provided for maintenance purposes but also for grinding operation. Both these technologies are based on the use of lasers and high speed cameras. The sampling step is 0.25 m, the cameras' sampling frequency is up to 460 frames/s and can work at speeds up to 320 km/h.

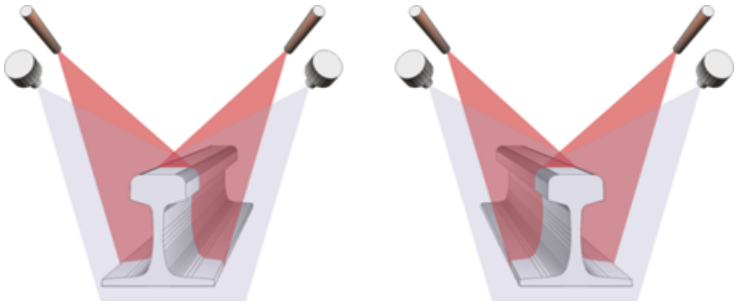


Figure 25 MER MEC Group Rail Profile Measurement System

MER MEC Group V-Cube is able to perform track surface inspection and measurement (*Figure 26*) in order to provide data on the track bed and the status of all its components.

The system can work at speeds up to 160 km/h and can perform:

- Rolling Surface Analysis
- Fastening Check
- Sleeper Check
- Track Bed Check

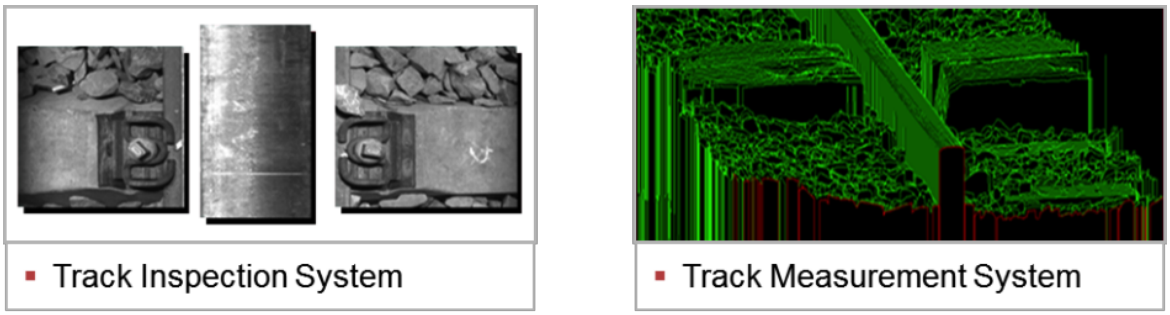
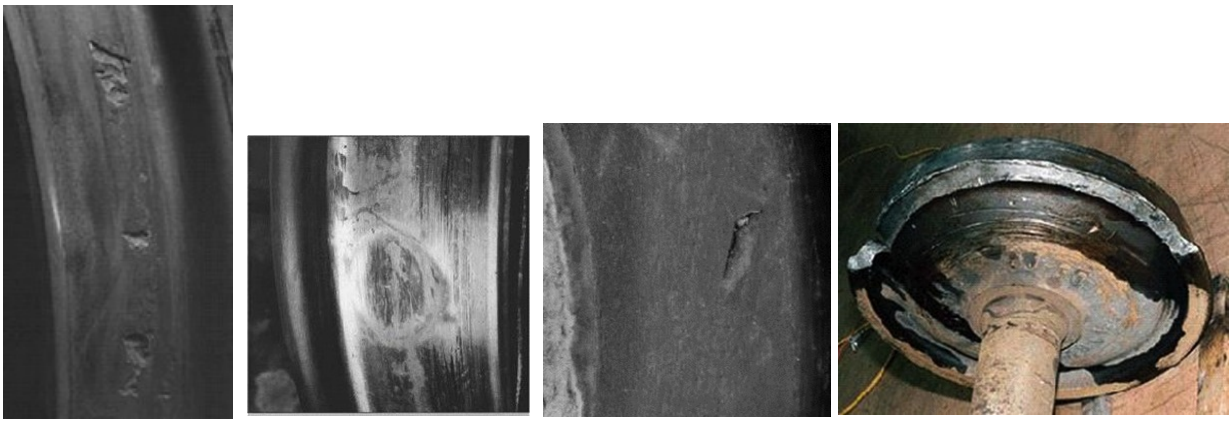


Figure 26 MER MEC Group V-Cube

MER MEC Group Wheel Surface Defects is a system able to detect surface defects of the wheels.

It is an innovative system based on vision technology of the running wheels by means of high-speed, high-accuracy cameras and advanced algorithms able to inspect the acquired images and detect eventual defects on the entire wheel rolling surface.

The system is able to detect different types of defects, as shown in *Figure 27* below.



Shelling Flat spot Grooving Broken flange

Figure 27 Types of wheel defects which can be detected with *MER MEC Group Wheel Surface Defects*

The detection of the wheel defects provides important data and information regarding the status not only of the wheels themselves, but also on the axles stressed by continuous shocks and vibrations.

The system has to be installed in the depot, and the main components of the equipment are (*Figure 28*):

- Camera boxes installed out of clearance
- Lighting system close to the rails

The processing functionalities of the systems are:

- Providing B&W images of each wheel
- 3D Representation of each wheel
- Automatic recognition and identification of the detected defect
- Generation of a “Mini-Movie” with a full frame colour matrix camera to understand the context
- Generation output such as tables containing information of the vehicle, the wheels and the defects
- Multi-criteria database search (by data, train number, type of defects, etc.)

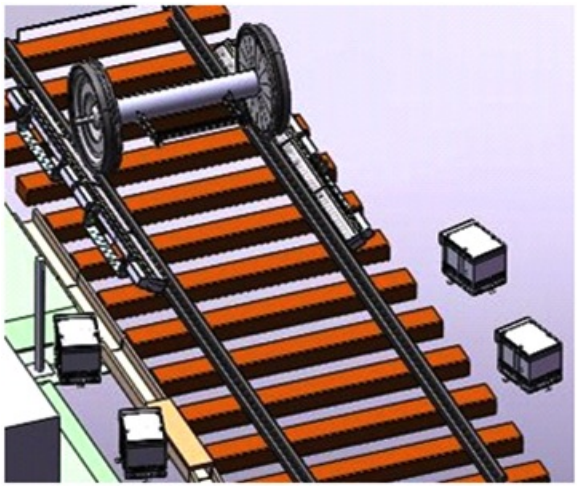


Figure 28 Example of W-inspect set up

MER MEC Group Thermal Inspection System is still the object of research and development and its capabilities regard the possibility of measuring the temperature difference between wheels and axle boxes.

The system is mounted in the depot, but could be also provided as a portable device.

3.3.2 Tests proposed by TRAIN

Consorzio TRAIN proposes to use different sensing technologies for monitoring the vehicle and telemetry measurements on the test track. TRAIN has a wide expertise in sensing technologies and considers both to employ systems dedicated to railway area and to adapt techniques developed in other domains.

More details on the general features and availability of state-of-the-art sensing technologies are presented in Appendix 2. Sensing technologies for railway monitoring and telemetry

Accelerometers are probably the most accurate type of sensors for vibration measurements and they cover the widest range of frequencies (from 1 Hz to around 1 MHz) – see *Figure 29*. Considering these characteristics, accelerometers are the most common sensing technology used in railway monitoring applications, for both vehicle and track monitoring.

Moreover, accelerometers are widely used for:

- vehicle and bogie vibrations monitoring;
- wheel-rail interaction monitoring by accelerometers mounted on axle boxes;
- subgrade stiffness changes detection, particularly in near bridges areas;
- track infrastructure anomalies detection;
- derailment detection.

Fibre Optic Sensors (FOS) are a promising alternative solution to accelerometers**,** even if they have a lower accuracy (see *Figure 29*). FOS can be used for telemetry purposes because they integrate telemetry – since optical fibre is by itself a data link. In addition, FOS present some further ***characteristics*** which made them useful for monitoring in railway applications:

- they are immune to any electro-magnetic signal (EMI), and to chemically aggressive and corrosive media;
- their accuracy is not affected on high and low temperatures (or, if measuring strain, temperature effects can be compensated);
- they are light-weight, miniaturised and flexible;
- they exhibit low thermal conductivity.

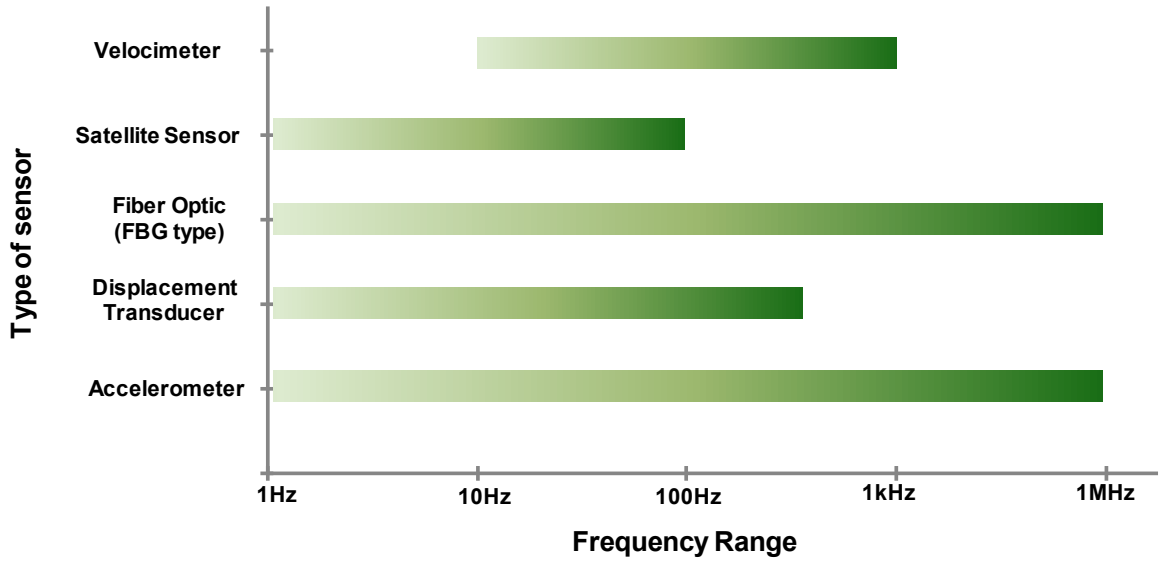


Figure 29 Operating frequency range of different types of sensors

Moreover, FOS allow for both short and long range measurements, having in both cases high sensitivity and multiplexing capability (i.e., they allow for a sensor network). FOS can be employed where continuous monitoring and data trending for long/large areas are requested. One weakness of FOS is their weakness – they are very fragile and need to be well protected, limiting their applications in areas such as wheelsets, where they can potentially be easily broken.

Some FOS applications in railway monitoring are depicted in *Figure 30* below [8]. Apart from these, FOS have been demonstrated to be a feasible sensing technology for:

- speed and weight measurement of the vehicle;
- strain monitoring at weld joints;
- vibration monitoring of the vehicle;
- structural integrity assessment of the vehicle bodyshell;
- fatigue monitoring, as a measure of the remaining lifetime of a system vs. the number of load cycles;
- deformation on the track induced by the single wheel;
- wheel ovalisation effect;
- ballast damage/deterioration.

In summary, FOS offer a unique advantage, over other monitoring technologies, of both point and distributed measurements.

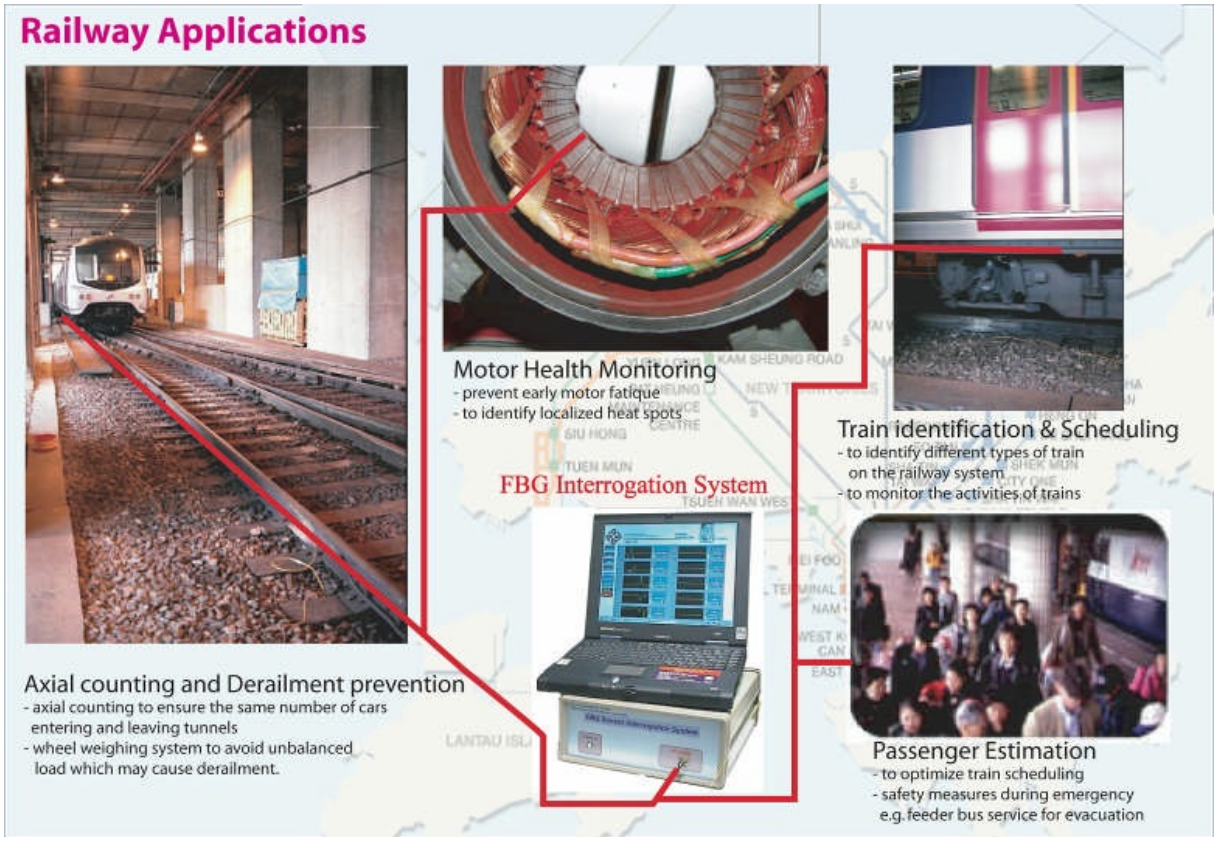


Figure 30 Fibre Optic Sensors (FSO) in monitoring and telemetry of both track and vehicle [8]

When high-accuracy, dynamic point measurements are requested (such as, for instance, with reference to the evaluation of fatigue and track deterioration), Fibre Bragg Grating (FBG) FOS technology is nowadays widely used. Very precise measurements of strain at specific locations can be performed, and several sensors can be multiplexed (multiple gauges can be installed on a single fibre) in order to allow a quasi-distributed monitoring. The FBG sensors are an internal stripe pattern in the core of the optical fibre that reflects one wavelength (or colour) of light. FBG measure the length change between two transverse "scores" (or grates) and are useful in applications where a large number of sensors are required, such as instrumentation along track areas for localised induced stresses, for instance close to abutments, bridges and switches/crossing zones.

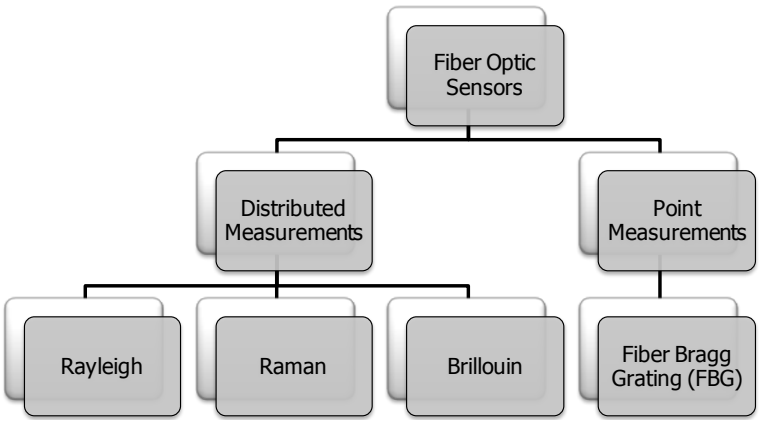


Figure 31 Experimental track monitoring using different FOS [5]

FOS technologies can also satisfy the demand for long range measurements (*Figure 31*), as for instance along kilometres of railway track. In such cases, distributed measurements can be performed employing FOS based on Rayleigh, Raman or Brillouin scattering. The latter allow measuring strain changes at all points along the fibre length, offering measurement distance from 30 up to 200 km, with a spatial resolution from 1 to 4. In general, only static measurements can be performed in any of these distributed modes, due to the relatively high processing times and the lengths involved.

Table 10 reports the performance of FBG and Brillouin-based FOS.

Table 10 Evaluation of FBG and Brillouin fibre optic sensing technologies

FSO type	Sensing Parameters	Strain resolution	Spatial resolution	Advantages
Brillouin	Temperature, Strain	20 μstrain	1m	Infinite sensing points Fiber integrated
FBG	Temperature, Strain, Pressure, Rotation	1 μstrain	0.1m	Linearity in response High resolution

In recent years, Consorzio TRAIN has gained considerable experience in the use of FBG for track telemetry and monitoring purposes. An example of an experimental campaign is presented in *Figure 32* below. The experimental set up was aimed at track deformation measurements and track load tests (i.e., measurements of effects correlated to unbalanced load), employing FBG sensors. The number of sensors and their locations were investigated. Two main configurations were tested: in one case the FBG sensor is incorporated in the sleepers, while in a further case sensors were directly attached to the rail. Deformations were induced by the transit of a load freight train drawn by an E656 class locomotive, running at a maximum speed of 91 km/h.

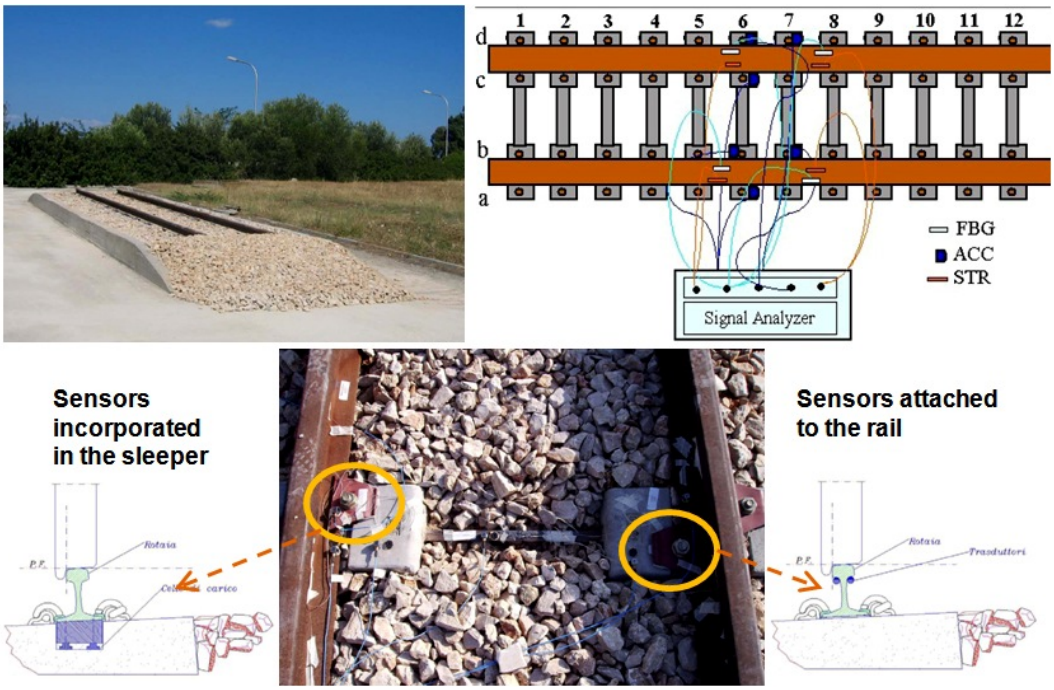


Figure 32 Experimental track monitoring using FBG FOS

Finally, for telemetry purposes, satellite sensors in outdoor environments can become a promising solution. Such a solution for vehicle telemetry, employing satellite based enhanced odometry systems, has been implemented within the GRAIL-2 EU project [7]. The system was used as a suitable method for train positioning/tracking, but not for train health monitoring. To make this solution effective for vehicle telemetry, satellite systems need to be integrated with inertial platforms, which would allow the monitoring of the train health at a global (the vehicle itself) and at a component (axle) level. The hybrid solution (*Figure 33*) will be composed by a satellite sensor receiver plus embedded antenna, integrated with the inertial platform comprising a 3-axis accelerometer, an odometer, a 3-axis gyroscope and a magnetometer.

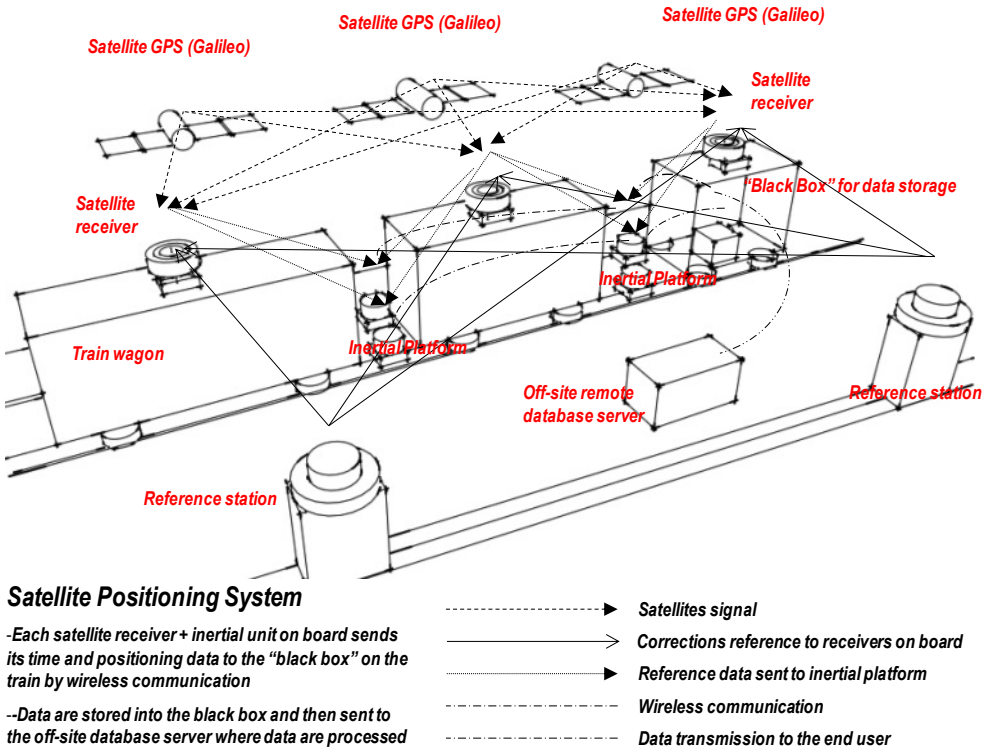


Figure 33 Example of an integrate satellite/inertial systems for telemetry purpose [7]

This type of solution may also be useful for monitoring track anomalies, such as valleys, using satellite sensors fitted to multiple train wagons. Comparing the response of each wagon to the same track geometry, recorded differences in performance can be used to identify track geometry features and to detect anomalies. Satellite sensors installed on the freight train vehicle may overcome the need for a dedicated instrumented rail wagon and may be an effective way to do telemetry of both the vehicle and the track at the test site.

4. PERFORMANCE BENCHMARK OF KEY VEHICLE COMPONENTS AND INFRASTRUCTURE

Considering the testing capabilities on the test track and selected routes, presented in previous sections, a benchmark methodology has been developed to evaluate both the vehicle and the track performances. The existing freight vehicle solutions, as well as key locations on the selected routes, will be evaluated against the improvements to be made through the novel technical SUSTRAIL outcomes. The sections below briefly present the proposed methodologies developed based on the testing capabilities which were identified and correlated within the Task 1.6 of WP1 activities.

4.1 Vehicle Benchmark

The vehicle benchmark consists of a series of interconnected activities designed to enable the comparison of performances between an initial selected type of freight wagon in operation and the final vehicle which has to be developed by SUSTRAIL project. Both the performances of the whole wagon and of its key components will be measured and compared within Task 6.3 (*Telemetry of track sites, test site and vehicle components*).

The vehicle benchmark comprises the following ***main activities and steps***:

- The information on the most common freight wagon in exploitation on selected routes and wider, in SUSTRAIL partners' countries, which was captured and analysed within Task 1.3 Rolling Stock, enabled a much deeper analysis to define the future vehicle requirements and specifications in WP2 and WP3.
- WP2 will finalise the definition of the requirements for the whole system, including the specific ones for the vehicle in *Task 2.4: Future vehicle performance requirements*.
- Based on the requirements defined in Task 2.4 and the available data captured in Task 1.3, one or more types of freight wagons will be selected for upgrade, and their specifications will be defined within WP3.
- Considering different criteria (possible achievements in WP3, availability of resources, partners' interest, etc.) a single type of wagon will be selected for developing a similar prototype, including the novel technical solutions, within WP3 and WP6.
- A wagon of the same type as that which was selected for upgrade will be instrumented and its performance will be measured on the test track, and monitored while the vehicle is in operation.
- The comparison of performances between the initial vehicle and the prototype (which will be measured in WP6) will allow a proper assessment of the improvements proposed by the developed technical solutions.

Considering both the available testing possibilities on the test track and the novel monitoring techniques proposed by the partners involved in these activities (MERMEC and TRAIN), which were detailed in the previous section, the proposed benchmark of vehicle will include the measurement and assessment of the following ***key components and parameters***:

- Braking system;
- Running gear (forces, accelerations, speeds, temperatures, etc.);
- Wagon body (accelerations, aerodynamics, etc.);
- Wheelsets and wheel-track contact;
- Noise level.

4.2 Infrastructure Benchmark

The infrastructure benchmark comprises a series of interconnected activities designed to enable the comparison of performances between the initial selected routes and the improved solution incorporating the technical outcomes resulting from *WP4 Sustainable track.*

The assessment of performances of initial selected routes has to consider the most common parameters which characterise the main components of the railway track:

- The track itself
- The track bed
- Auxiliary elements: switches, crossings, signalling, etc.

The benchmark of infrastructure methodology has to take into account the existing equipment in operation and usual track performance measurements carried out on the selected routes by Infrastructure Manager partners: Network Rail (NR) in UK, ADIF in Spain and NRIC in Bulgaria.

Network Rail regularly monitors and records the following track parameters:

Track geometry (as SDs and L2 exceedances, as detailed below):
- Track gauge and rail profile
- Broken rail or rail defect history per 100 km
- Immediate intervention actions required for geometry faults / 100 km
- Projected wear rates for side wear
- Projected development of Rolling Contact Fatigue (RCF)

Track Bed:
- High degradation rate – soft spots, water logging
- Ballast condition – wet beds, contamination
- Failure of a site to respond to maintenance treatment

S&C:
- Track geometry
- Gauge and rail profile
- Indications of sub-standard operation
- Side wear and RCF
- Visual inspection reports (detailed below)

Visual Inspection concerns:

i) *Rails and rail joints:*

- visible rail defects, including rolling contact fatigue and other cracks, breaks, rail head damage and significant corrosion;
- signs of corrugation;
- track buckling;
- excessive sidewear;
- check rails, for security, wear and flangeway obstruction;
- broken, cracked or defective fishplates;
- loose or missing fishbolts or multiple-groove locking pins;
- dipped joints;
- expansion gaps: joints in jointed track and adjustment switch settings in welded track;
- damaged end-posts and defective insulation at insulated rail joints, and lipping of rail ends;
- security of temporary rail clamping systems;
- loose or ineffective rail anchors;
- effectiveness of lubricators (is grease being applied correctly to the rails);
- detached signalling or electrical bonds.

ii) *Sleepers, bearers and fastenings:*

- broken, cracked or ineffective sleepers;
- broken, cracked or defective chairs and baseplates;
- vertical or lateral movement of chairs or baseplates;
- loose or missing fastenings, keys, pads or insulators;
- broken or missing chair and baseplate screws or through-bolts and associated ferrules or washers;
- loose or damaged gauge tie bars.

iii) Switches and crossings:

- broken, cracked, defective or worn switch rails and crossings;
- obstructions in switches and flangeways;
- evidence of damaged or inoperative drive mechanisms or related parts;
- evidence of wheels striking the back of the open switch;
- longitudinal position of check rails, to confirm that crossing noses are covered;
- wide flangeways to, and security of, check rails;
- evidence of irregular running contact band on the switch, stock rails and crossing;
- wheel strikes at crossing noses;
- damaged or loose stretcher bars;
- loose or missing bolts or multiple groove locking pins or studs;
- security of points clipped out of use.

iv) Track geometry:

- vertical and horizontal misalignments, and twist;
- cyclic top;
- gauge widening (not designed).

v) Track support:

- areas liable to subsidence or other earth movement, including if caused by burrowing animals;
- collapsed catch pits;
- signs of ballast voiding, slurrying or effects of inadequate drainage on ballast conditions;
- deficiencies in ballast provision (especially the profile in cribs and shoulders);
- excessive ballast, particularly in four-foot or heaped over fastenings;
- track drainage (signs of flooding, damaged catchpit covers, etc.);
- longitudinal rail-carrying bridge timbers and associated transoms, ties and packings.

The geometry of 18,500 miles of track is routinely recorded by Network Rail track recording vehicles at frequencies which vary according to line speed, traffic volume and tonnage. These measurements are of the vertical (rail top, both rails) and horizontal (centre line between the rails) geometry and rail-head profiles for every 200 mm along the track. These outputs are filtered:

1. For track at all linespeeds a short-wave (35 metre) filter is employed, which suppresses variations having a wavelength of 35 m or more. This gives 35 m vertical (top) and alignment (line) profiles.
2. For track at 128 km/h and above an additional pair of profiles, namely 70 m top and line, are obtained using a long-wave (70 metre) filter.

For each eighth-mile (220 yards – approx. 200 m) length of track, a single standard deviation (SD) is calculated for the recorded variations for each of the four profiles and is expressed in mm. *Table 11* below shows Network Rail standard targets to be achieved by 50%, 90% and 100% of track. The table was extracted from Company Standard NR/L2/TRK/001/C01/04. It

specifies threshold SD values for each of the four principal Track Geometry parameters, to be achieved by 50%, 90% and 100% of the track. Eighth-mile SDs which breach the Maximum threshold on either or both parameters are referred to as "super-red."

Table 11 Network Rail - Geometry Quality Band standard deviations [mm]

Speed band		35 m wavelength filter								70 m wavelength filter					
		Top				Line				Top			Line		
↓	Speed range mph	Good	Satis	Poor	Very Poor	Good	Satis	Poor	Very Poor	Good	Satis	Poor	Good	Satis	Poor
1	10–20	5.2	7.4	8.3	9.9	3.0	5.0	5.6	9.9						
2	25–30	4.3	6.1	7.0	7.7	2.7	4.5	5.2	8.6						
3	35–40	4.1	5.8	6.7	7.2	2.5	4.1	4.7	7.9						
4	45–50	3.8	5.4	6.3	6.7	2.2	3.7	4.5	7.3						
5	55–60	3.5	5.0	5.9	6.3	2.0	3.3	4.2	7.0						
6	65–70	3.0	4.3	5.4	6.0	1,7	2.9	3.6	6.7						
7	75–80	2.7	3.8	4.8	5.7	1.5	2.5	3.1	6.3	3.7 †	5.7 †	6.3 †	3.0 †	5.2 †	5.7 †
8	85–95	2.2	3.2	4.0	5.3	1.3	2.1	2.7	6.0	3.3	5.1	5.6	2.6	4.5	5.0
9	100–110	1.9	2.7	3.4	5.0	1.1	1.8	2.3	5.7	2.9	4.5	5.0	2.2	3.8	4.3
10	115–125	1.7	2.4	3.0	4.7	1.0	1.6	2.0	5.0	2.4	4.0	4.4	1.8	3.2	3.7
† These values apply to 80 mph track only.															

Discrete track faults – Level 2 exceedences

Unlike the eighth-mile SD-based parameters discussed above, these are distortions in track geometry identified for a short length of track. They include the following ***categories:***

- *Top:* Individual top measurement exceeds threshold value, either rail.
- *Alignment:* Individual alignment measurement exceeds threshold value.
- *3m twist:* Detected by an algorithm which combines the top measurements on both rails.
- *Gauge:* Detected by the alignment measurement system.
- *Cyclic Top:* Based on detection of a cyclic variation in successive top measurements on either rail. This cyclic variation can inter-react with the natural frequency of the vehicle suspension thus magnifying the effect of the track fault.

Considering Network Rail track monitoring procedures, and the availability of similar data to ADIF and NRIC, the main parameters will be selected and considered for SUSTRAIL track performance benchmark.

Considering the availability of the proposed parameters in Infrastructure Managers' databases, and the existing equipment which is regularly used to monitor the selected routes (presented in Section §2.3), a number of relevant locations will be chosen on each route. The selected locations include sections of straight line, curve line, bridges, switches, crossings, etc.

The proposed locations on the selected routes will be periodically monitored and the measured parameters will be assessed and compared (between routes, before/after the implementation of SUSTRAIL infrastructure improvements).

5. CONCLUSIONS AND FUTURE WORK

Task 1.6 of WP1 activities has been successfully accomplished, and enables some preliminary results, conclusions and suggestions for further work.

The main ***conclusions regarding the preliminary tests and analysis of testing possibilities on the test track*** are presented below.

- The AFER test track at Faurei, which was recently modernised, offers good conditions for future SUSTRAIL demonstration activities, allowing a wide range of standard tests, especially those required for modified or new vehicles.
- However, for the scientific purposes of SUSTRAIL project, some other valuable testing procedures and equipment has been proposed by partners MERMEC and TRAIN. If implemented, the proposed tests would offer a wider variety of data, at different detail levels, which would enable useful comparisons within vehicle benchmarking.
- The test track offers also some possibilities to measure and record the track performance within the project duration. However, since the testing activities on the test track have significantly reduced in the past years, due to recession and decline of railway industry, just minor and insignificant modifications of the track are expected to appear in the next 2-3 years. Thus, the option to benchmark the test track performance should be reconsidered and eventually replaced with other more significant testing options on locations chosen on selected routes.

Some ***conclusions regarding the methodologies and activities to benchmark the vehicle and track performance*** are reported below.

- The wide variety of tests available both at AFER test track (already validated by the preliminary tests) and suggested by other partners (i.e., MERMEC and TRAIN) demonstrate the feasibility of a strong and significant testing programme to evaluate all vehicle technology improvements targeted by SUSTRAIL project.
- Some of the existing test facilities and, especially, the proposed new ones should be updated and validated by the time when the initial type of vehicle will be selected and tested.
- The benchmark of track performance should consider mainly the potential assessments and comparisons between different locations on selected routes. However, the possibility of demonstrating some infrastructure improvements on the test track exists and should be considered within the limits of available resources.
- The procedure and methodology used and proposed by Network Rail for the benchmark of track performance offers sufficient information to perform such activity. However, the track monitoring activities should be limited in terms of number of measured parameters, considering both the possibilities of the other Infrastructure Manager partners and available resources.
- The track performance benchmark methodology and selection of parameters and locations to be monitored must be finalised by the time the improvements targeted by WP4 are defined.

Based on these conclusions, some ***future testing work*** can be suggested.

- Considering the wide range of available and suggested tests for the vehicle benchmark, a realistic testing programme should be developed, to take into account both the standard demonstration requirements, scientific objectives and available resources. Partners directly involved in vehicle demonstration activities should closely collaborate to define this testing programme.
- The details of track performance benchmark (i.e., parameters and locations on routes) should be decided as soon as possible (following an agreement between Infrastructure Managers and WP1 and WP4 leaders).
- Selected track parameters and characteristics of selected routes should be gathered to define the initial status before any technical improvements.
- Depending on the type of wagon which will be selected for upgrade, and the foreseen outcomes of WP3, a series of supplementary vehicle tests may be necessary (on a similar type of wagon) to capture all characteristics to be used in benchmark.

APPENDICES

Appendix 1. Infrastructure measurement technology (Network Rail)

a. N etwork Rail New Measurement Train (NMT)

The NMT is owned and operated by Network Rail, Britain's infrastructure manager. The train is run over the main rail network (excluding the Southern region) every two weeks at speeds of up to 176 km/h.



Figure 34 New Measurement Train (Copyright Network Rail)

Data is collected on:

- Track geometry
  - Top (vertical left and right rail profiles)
  - Crosslevel
  - Cant
  - Gauge
  - Curvature
  - Cyclic top
  - Lateral alignment
- Rail
  - Profile
  - Wear
- Overhead catenary
  - Position
  - Wear
- High definition cameras
  - Track ahead
  - Wheel/rail interface
  - Individual clips and sleepers
  - Check the six foot
  - Observe vegetation
  - Signal sighting.
  - Microphones to monitor 'excessive bogie noise'
  - Radio survey to check the state of the radio communications infrastructure

b. Network Rail Southern Measurement Train (UFM160)



Figure 35 Southern Measurement Train (Eurailscout UFM160)

The Southern Measurement Train covers the area directly south and south-east of London which has 3rd Rail 750V DC supply. The train runs at speeds of up to 160 km/h. Data is collected on:

- Track geometry
  - Top
  - Alignment
  - Cant
  - Twist
  - Cyclic top
- Rail
  - Height
  - Head width
  - Cant
  - Type.
- Rail surface
  - Rail cracks
  - Rail joints
  - Burns
  - Wear on welded joints
  - Short wave wear
  - Missing fasteners
- Video observation
  - Rail, track
  - Rail surroundings
  - Signal visibility
  - Vegetation check
  - Third rail position
- D-GPS Positioning

c. Network Rail Track Recording Unit (TRU)

The track recording unit can operate at up to a maximum speed of 120 km/h. It records track geometry in the same way as the new measurement train and is also fitted with radio survey and ground penetrating radar equipment which is used to identify voids, wet spots and other issues underground.

d. Network Rail Ultrasonic Test Units (UTU)

Network Rail owns thee ultrasonic test units (UTU). They are diesel powered and can transit between tests at 96 km/h. During tests they run at 48 km/h and detect cracks within rails in order that they can be rectified before they reach dangerous length. Network Rail carries out rail inspection using the ultrasonic methods as described in Specification NR/TRK/SP/055. Network Rail uses both the manually operated 070 portable ultrasonic test equipment and the ultrasonic test unit vehicle. The testing frequencies are shown below.

Table 12 Specifications for testing frequencies in ultrasonic rail inspections

Track Category	Pedestrian UT Inspection Interval (weeks) Plain Line	Pedestrian UT Inspection Plain Line Maximum Interval Between Inspections (weeks)	Pedestrian UT Interval S&C, Adjustment Switches, Level Crossings, Tunnels, Joints (see 4.3). (weeks)	Pedestrian UT Inspection S&C, Adjustment Switches, Level Crossings, Tunnels, Joints (see 4.3). Maximum Interval Between Inspections (weeks)	Interval (weeks) UTU	Maximum Interval UT Inspection (weeks) Plain Line UTU Compliant Routes
1A	13	15	8	10	8	10
1	26	30	13	15	8	13
2	52	56	26	30	16	26
3	104	112	52	56	26	34
4	104	112	52	56	26	34
5	104	112	52	56	26	34
6	104	112	104	112	52	78

e. Ground Penetrating Radar

Ground Penetrating Radar is a non-intrusive investigation technique used to examine the depth and condition of the track bed. Radar is fired into the trackbed and reflections occur at the boundaries between materials that have different radar conductivities, e.g., a radar pulse moving from dry ballast to wet clay will produce a strong reflection while a radar pulse moving from ballast contaminated with moist fines to a moist silt layer will produce weaker reflections. These reflections make up a Radargram. The standard Radargrams are based on 1 GHz antenna data for assessing ballast condition; these are augmented by output from a 400 MHz antenna which looks at deeper layers providing an interpretation of ballast layer depths. This Ground penetrating radar was developed by GSSI and is fitted onto two of the Ultrasonic Test Trains (UTU) and the Track Recording Unit (TRU).

Current benefits include a reduction in the need for trial holes (less need for workers on the track and possessions) and better targeted maintenance & QC of maintenance done.

Future benefits:

- high output ballast cleaner optimisation – being able to tell how deep the ballast needs to be cleaned means that less time is spent cleaning ballast that is clean enough, allowing more time on ballast hat does require cleaning;
- residual ballast life prediction;
- combined with track geometry data to produce exceedance type reports & monitoring of trackbed deterioration.

The diagram below demonstrates the output of Ground Penetrating Radar which shows soft clay under a thin chalk bed which is not supporting the track bed. The large dip in the brown ballast layer shows that ballast has been added to the site over a number of years.

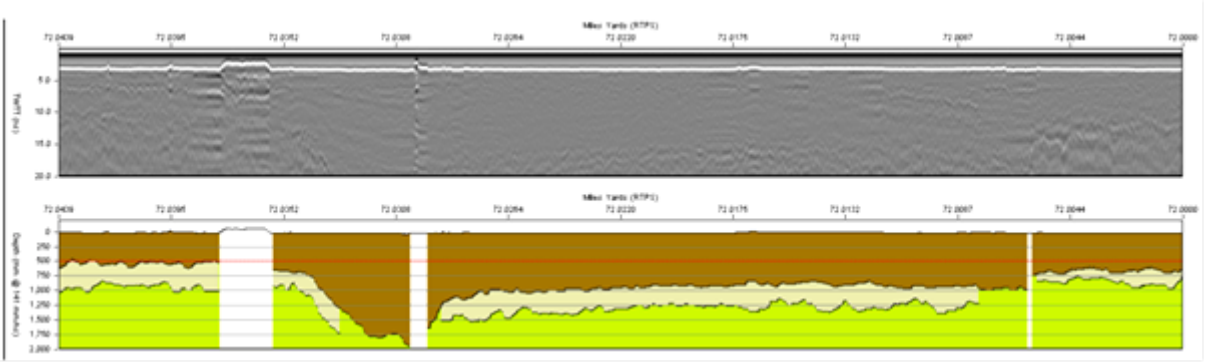


Figure 36 Example of Ground Penetrating Radar output

f. WheelChex – Wheel Impact Load Detector on Network Rail

'WheelChex' is a lineside (wayside) measurement system that monitors rolling stock as it passes. The system consists of loading (force) measurement components that are connected to a PC based logging system. The WheelChex system is capable of rapid interpretation of complex information to provide data on the condition of individual wheels and axles. Since trains in the UK are not routinely tagged, the data from a WheelChex system is uploaded to a central server each night where it is combined with other data and passed on to the appropriate TOC/maintainer. The maintainer uses this information to identify and rectify faulty wheelsets.

WheelChex® was developed by AEA Technology Rail and first installed on UK infrastructure in 1998. Currently there are 28 installations across the UK, listed in *Table 13*. The original need for the technology came from the Infrastructure owner, Network Rail:

"As WheelChex was originally perceived to be a track "tool", it was assumed to be an aid to remove vehicles that failed to meet the Railway Group standard limits. However, as the System team recognised, the actual data "owner" should have been the train operator as early detection of deterioration was perceived to be a better use of the system."

The system uses a series of strain gauges attached to the rail with equipment positioned between sleepers and trackside. The device is sufficient in length to recorded rail stresses for the complete wheel circumference. All recorded data is sent electronically to a central support centre where it is post-processed and presented using software developed in-house.

Table 13 WheelChex Wheel Impact Load Detector (WILD) Sites

Equipment	Route	Location	Area
WILD	Anglia	Eastrea	-
WILD	Anglia	Ingatestone	-
WILD	LNE	Croxton	Great Northern
WILD	LNE	Sessay	North Eastern
WILD	LNE	Wymondley	North Eastern
WILD	LNW	Ainsdale	Liverpool
WILD	LNW	Cheddington	West Coast South
WILD	LNW	Dallam	Preston
WILD	LNW	Grindleford	Manchester
WILD	Kent	Swanley	-
WILD	Kent	Sevington	-
WILD	Sussex	Salfords	-
WILD	LNW	Heaton Chapel	Manchester
WILD	M & C	Thurmaston	East Midlands
WILD	Scotland	Braidwood	Scotland West
WILD	Scotland	Howwood	Scotland West
WILD	Scotland	Innerwick	Scotland East
WILD	Scotland	Philipstoun	Scotland West
WILD	Wessex	Queenstown Road	-
WILD	Western	Alderton	West Country
WILD	Western	Bromfield	Wales & Marches
WILD	Western	Cholsey	Thames Valley
WILD	Western	Eckington	West Country
WILD	Western	Exminster	West Country
WILD	Western	Marshfield	Wales & Marches
WILD	Western	Waltham	Thames Valley

Faulty wheels are identified in real time and fault reports are sent immediately to notify the Infrastructure owner and the relevant RS operator of severe wheel faults causing dynamic impact loads over 350 kN

There are four levels of alarm at WheelChex sites: level 1 (200-350 kN), level 2 (350-400kN), level 3 (400-500 kN), and level 4 (> 500 kN). A level 1 alarm is advisory and the control centre does not need to stop the train. A level 2 alarm requires a 30 mph (48 km/h) speed restriction for a freight train until it reaches a suitable location where it can be taken out of service. Levels 3 and 4 require 20 mph (32 km/h) and 10 mph (16 km/h) speed restrictions respectively.

A report by the UK Rail Accident Investigation Board (RAIB Report 02/2009) shows a WheelChex output for a train recorded at Eastrea on the EMP route near Peterborough (*Figure 37*).

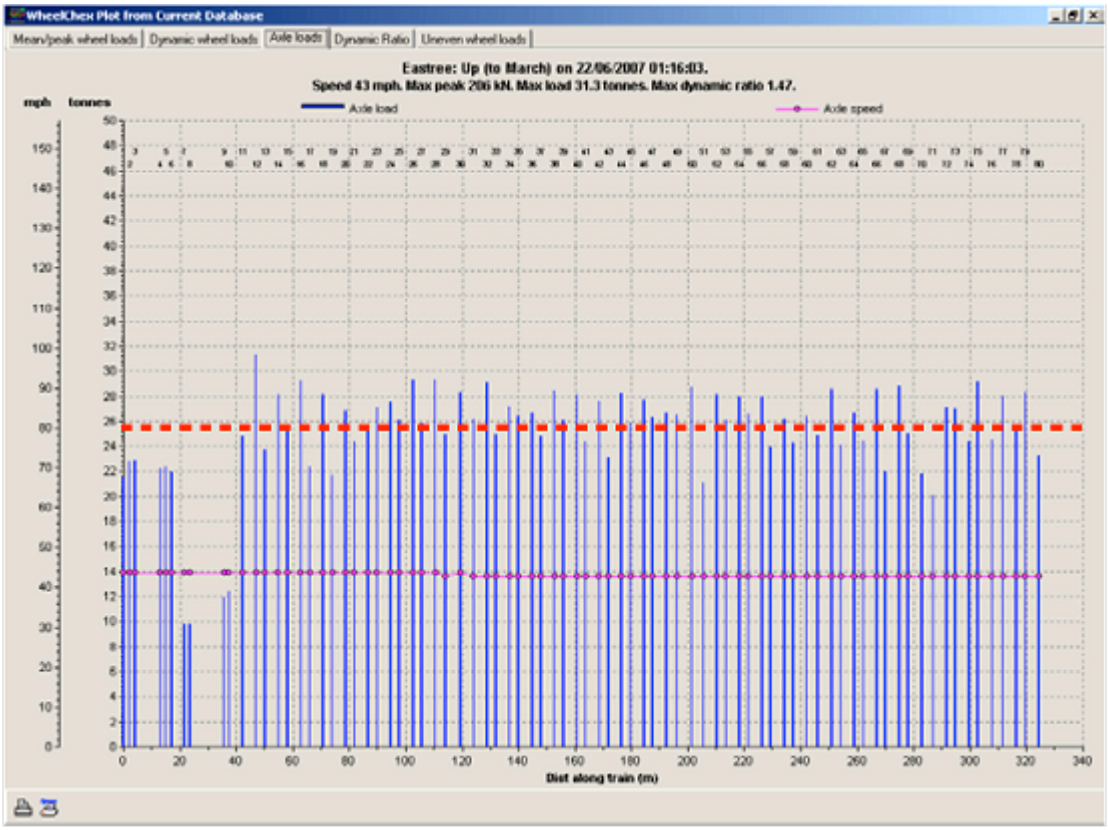


Figure 37 Example of WheelChex output (RAIB Report 02/2009)

This was made up of two-axle PHA aggregate wagons. The red dotted line shows the maximum permitted axle load of 25.5 tonnes. The print out of individual axle loads along the train shows the uneven loading between ends with most of the rear axles being heavier. The total load of 52% of these wagons was above the permitted level. A Co-Co loco is seen at the front of the train followed by a 4-axle bogie wagon.

The table below in the report also showed that the WheelChex could record uneven loading between wheels and identify cases of frame twist on wagons. This is shown on the PHA wagon 16002. The frame twist was thought to have been caused by a derailment 2 years earlier.

Table 14 Example of measured uneven loading (WheelChex RAIB Report 02/2009)

16002	LEFT WHEEL (kN) (Tonnes)		RIGHT WHEEL (kN) (Tonnes)	
LEADING AXLE	157.2 kN	15.00 T	96.2 kN	9.81 T
TRAILING AXLE	111.7 kN	11.39 T	156.8 kN	17.0 T

g. The Gotcha Asset Management System on Network Rail

The Gotcha Asset Management System's wheel-impact detection application has been in continuous use in the Netherlands for over 7 years. The system is currently installed in a number of light and heavy rail networks throughout Europe.



Figure 38 The Gotcha system installed on the rail

There are now 3 systems installed on Network Rail including one at Banbury at the test centre near 86 miles on the DCL route between Didcott and Leamington Spa and one at Shawford on the BML1 route between Southampton and Basingstoke. Gotcha was installed at Banbury on 17 December 2007 and detect wheel loads and wheel unbalanced loads. There is also a portable system.



Figure 39 The Gotcha system installed at Shawford on BML1 near 69.5 mile post

The basic components of the Gotcha system are a set of fibre-optic sensors bolted to the rail linked to a trackside data analysis and storage capability with high-speed data links to operations, analysis and maintenance centres. The Gotcha system determines the local bending of the rail around each fibre optic sensor to determine the static and dynamic wheel impact load. Gotcha generates the following data of use to infrastructure and maintenance staff:

- Accurate and reliable identification of train or vehicle types;
- Cumulative tonnages over each section of route;
- Advanced warning of wheelset problems for operators;
- Record of train speeds, lengths and loads;
- Definition of type of problems with each wheel within train consist;
- Dynamic and static load for each axle and vehicle, identifying overload and imbalance on any vehicle;
- Permanent audit trail for allowing time series analysis of faults and incident investigation data for each vehicle.

Figure 40 shows the measured deflection of the rail as the bogie passes over a single sensor. Data combined from multiple sensors ensures a high accuracy of output.

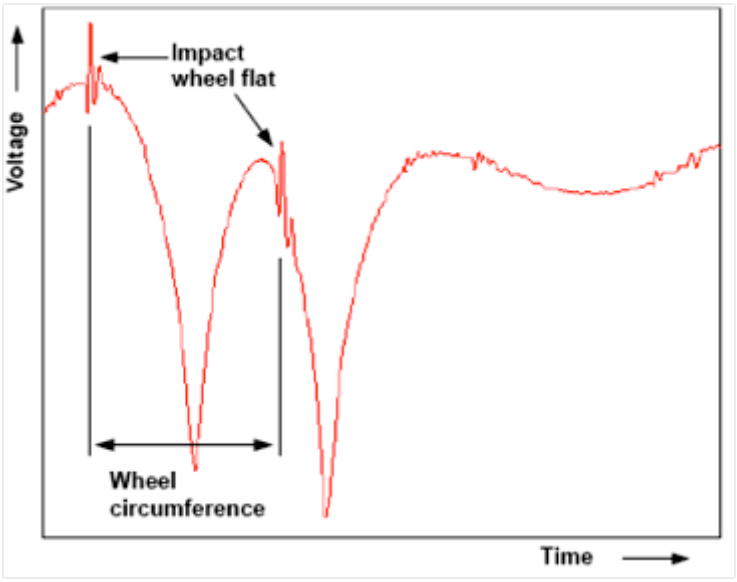


Figure 40 Example of Gotcha system measurement using a single sensor

Appendix 2. Sensing technologies for railway monitoring and telemetry

a. Requirements of a sensing network

Within any monitoring study, the first required action is to select an appropriate ***sensor network*** that can be adequate to observe and record the dynamics of the system and is suitable for signal processing and data analysis purposes.

In general, a sensor network is composed of ***three main elements***:

- the sensing unit;
- the communication, and
- the computation modules, which include the hardware and software as well as the processing algorithms.

Any monitoring sensing network aims at correlating the sensor reading to phenomena and anomalies (for instance, cracks and damage in the railway vehicle structural elements) which are occurring on the monitored system. To comply with this need, some designed ***parameters*** have to be defined prior the implementation of the monitoring solutions:

- Types of data to be acquired;
- Sensor topology (i.e., types, numbers, and locations of sensing units);
- Sensitivity and accuracy;
- Data acquisition/telemetry/storage system;
- Communication on-site and off-site;
- Power requirements;
- Sampling rates and sampling intervals: continuous (real time) monitoring, monitoring at periodic intervals (offline);
- Processor/memory requirements.

Given this design parameters, a designed ***sensing system*** mainly consists of:

- Transducers - convert changes in the field variable of interest (i.e., acceleration, strain, temperature) to changes in an electrical signal (i.e., voltage, impedance, resistance);
- Analogue to digital (A/D) converters - transfer the analogue electrical signal into a digital signal that can subsequently be processed;
- Signal conditioning;
- Power supply unit;
- Telemetry;
- Processing and memory for data storage.

b. Sensing network types and general characteristics

The number of sensing systems available for monitoring purposes is enormous and these systems can significantly vary depending on the specific monitoring activity. Considering the existing wide variety, sensing network types and characteristics are usually a direct consequence of the type of communication system chosen for the monitoring purpose. Conventionally two types of communications systems have been used: ***wired*** and ***wireless***.

A conventional wired sensor network is the one where sensors are connected via conductive cabling to a centralized data processing (data logger) and multiplexing unit. Each sensor is independent of other sensors in the network (i.e., each sensor has its own cabling) and controlled synchronised interrogation of the entire network is achieved only through the central unit. Within such type of configuration, the information can be provided only from sensors to the data loggers and not vice versa (i.e., the data logger cannot pass information back to an individual sensor). In applications demanding control and/or feedback this is a

drawback and the reason why in such type of cases, actuator arrays can take the place of some of the passive sensor arrays.

Nowadays, the majority of sensor networks employ a wired architecture. Wireless communication protocols are now standardised with such protocols as IEEE 802.11 through 802.15, and bandwidths are now approaching that of conventional wired networks. Furthermore, increases in chip real estate and processor production capability have reduced the power requirements for both computing and communication. Considering these advantages, wireless sensor network are currently matching some issues that are relevant for monitoring purpose - wireless sensors network can:

- support a large number of individual sensor nodes, densely deployed in possibly random configurations in the sensing environment;
- help in exchange information between an individual node and a user directly via a point-to-point protocols;
- improve cooperation between sensor nodes to perform data fusion in such a way that only required information are processed and transmitted offsite.

c. Sensing network paradigm

Any sensing network is designed to supply measurements suitable to the monitoring of a chosen system. Across any monitoring purpose, the most common and most ***useful measurements*** recorded can be summarised as follows:

- Displacement;
- Velocity;
- Acceleration;
- Strain;
- Temperature;
- Impedance;
- Corrosion;
- Fatigue.

Different types of sensors are suitable for recording the aforementioned parameters. *Table 15* below resumes some of the most common sensor types used for the measurement of acceleration, displacements, strain, vibrations and temperature.

Moreover, the sensors' sensitivity is often subject to the environmental conditions around the monitored system. For instance, temperature dependence can become a relevant issue for laser sensors, while indoor operability represents the trade-off condition of satellite system operability, as shown in *Table 16*.

For all sensing technologies in tables below, *Figure 41* and *Figure 42* depict the accuracy of vibrations measurements with respect to weather conditions, respectively as function of temperature variations. These diagrams clearly visualize the dependence of sensing technologies to environmental conditions, which, in an outdoor environment as the railway is, may significantly decrease the accuracy of measurements. Thus, the above tables and below figures offer some suggestions and examples of which technologies are most feasible and recommended for railway telemetry applications, involving both the track and the vehicle.

Table 15 Sensor types and measuring capabilities

Sensor / Measurement	Accelerometer / Velocimeter	Fiber Optic	Laser sensor / Displacement Transducer	Satellite Sensors
Displacement	Indirectly, through integration	Directly from strain	Directly, but relative displacements	Directly (both absolute and relative)
Acceleration	Directly	Directly by fiber optic accelerometers	No	Indirectly, through double derivation
Strain	No, in principle	Directly	Indirectly, from displacements	From displacements
Temperature	No	Directly	No	No
Vibrations	Yes	Yes, in principle	Yes, in principle	Depending on the frequency range

Table 16 Sensors' sensitivity dependence on environmental constraints

Sensor / Dependence	Accelerometer / Velocimeter	Fiber Optic	Laser sensor / Displacement Transducer	Satellite Sensors
Weather Condition	Yes, but low relevance on accuracy	Yes, but not so relevant on accuracy	Yes, low to medium relevance on accuracy	No
Temperature Variations	No	Yes, but can be compensated	Yes, can be high	No
Indoor Operability	Yes	Yes	Yes	No, in principle

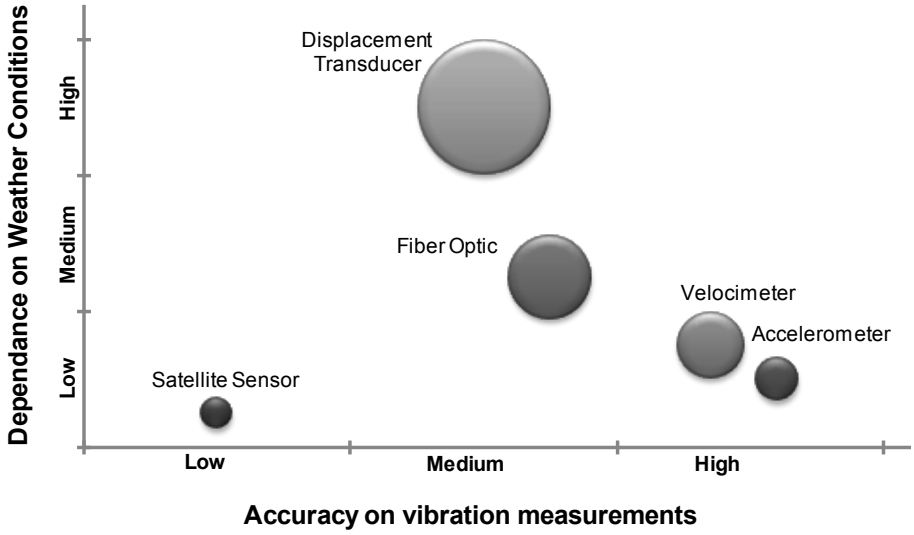


Figure 41 Vibration measurements' accuracy as weather conditions function

For instance, looking at *Figure 41*, it can be noted that velocimeters and accelerometers are very accurate and not strongly dependent on weather conditions (fog, rain, snow, etc.), while, on the contrary, displacement transducers like laser sensors can suffer from atmospheric condition variations. Moreover, *Figure 42* clearly shows that accelerometers and velocimeters accuracies do not depend on temperature variations, as those from day and night.

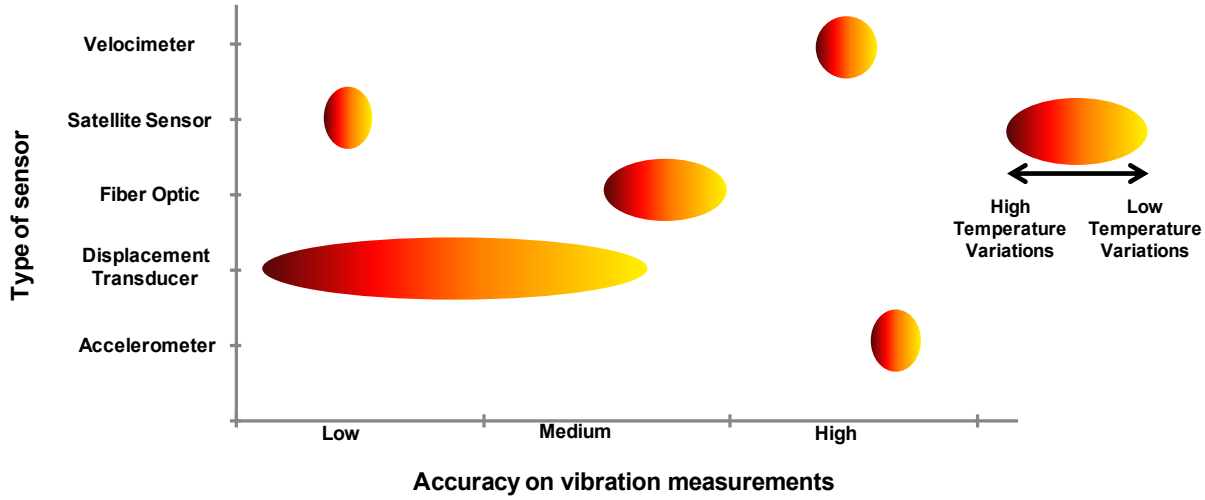


Figure 42 Vibration measurements' accuracy depending on temperature variation

However these figures just give a partial view in identifying the most suitable sensing technologies, since they account only for vibration monitoring. The aim of these figures is to exemplify a particular case, showing benefits and drawbacks of some sensing technologies, and not to assess all the sensing technologies in a holistic approach for a number of different applications. Given this, it is worth noting that if accelerometers are the most feasible sensors for vibration monitoring, they may not be the most appropriate for other monitoring purposes.

Appendix 3. Romanian S78 Wheel Profile

The file S78.mpt below is not an official MiniProf reference file. It is based on equations describing the Romanian S78 wheel profile.

```
;FJF Guesswork Ltd.
;wheel reference profile RO S 78.
;Made by Francis Franklin, 15/2-2012
;from equations, modified
;
*S78_FJF
#100
;
L 60 -2.8210003 32.158 -0.964000152
A 27.368 -72.805 72 86.18542172 89.89893656
A 28.374 499.194 500 -94.86797437 -90.10072603
A -7.267 80.709 80 -106.1318533 -94.86811813
A -22.506 27.862 25 -107.9796992 -106.2337072
A -26.211 16.446 13 -159.9999476 -107.9758069
L -38.427 11.99101164 -39.761 15.66325885
A -58.558 8.835 20 19.97361889 63.59265505
A -55 16 12 63.59265505 130.322057
A -49.5 9.519 20.5 130.3212932 180
```

REFERENCES

1. BS EN 12663-2:2010, Railway applications. Structural requirements of railway vehicle bodies. Freight wagons, April 2010
2. BS EN 13848-5:2008, *Railway applications. Track. Track geometry quality. Geometric quality levels. Plain line*, April 2008
3. BS EN 14363:2005, *Railway applications. Testing for the acceptance of running characteristics of railway vehicles. Testing of running behavior and stationary tests*, April 2006
4. ERRAC Roadmap FP7 project, WP 01 The Greening of Surface Transport, Deliverable "*Energy Roadmap for the European Railway sector*"
5. G. Honglei Guo, X. Gaozhi, M. Nezih and Y. Jianping Yao, *Fiber Optic Sensors for Structural Health Monitoring of Air Platforms, Sensors*, 11, 2011, pp. 3687-3705
6. G. Park, C. R. Farrar, M. D. Todd, W. Hodgkiss, T. Rosing, *Energy Harvesting for Structural Health Monitoring Sensor Networks*, LA-14314-MS, February 2007
7. GRAIL-2 FP7 project, *GNSS-based Enhanced Odometry for Rail*, available at http://www.gsa.europa.eu/go/randdxv-2/project-portofolio
8. H.Y. Tam, T. Lee, S.L. Ho, T. Haber, T. Graver, A. Mendez, *Utilization of Fiber Optic Bragg Grating Sensing Systems for Health Monitoring in Railway Applications*, Micron Optics Documents Library, 2007, available at http://www.micronoptics.com/sensing_doc_library.php
9. RSSB, Railway Group Standard GM/RT2000 *Engineering Acceptance of Rail Vehicles*, December 2009
10. RSSB, Railway Group Standard GM/RT2043 *Braking System and Performance for Freight Trains*, April 1998
11. UIC, Leaflet UIC 540 *Brakes - Air Brakes for freight trains and passenger trains*, November 2006, ISBN: 2-7461-1172-1
12. UIC, Leaflet UIC 541-1 *Brakes - Regulations concerning the design of brake components*, September 2010, ISBN: 978-2-7461-1853-9
13. UIC, Leaflet UIC 544-1 *Brakes - Braking power*, October 2004, ISBN: 2-7461-0774-0
14. UIC, Leaflet UIC 571-1 *Standard wagons - Ordinary bogie wagons - Characteristics*, February 2001, ISBN: 2-7461-0276-5