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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PERFORMANCE ANALYSIS OF VEHICLE AND INFRASTRUCTURE UPGRADES FOR HIGHER FREIGHT CAPACITY

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Executive Summary

During May 2015, a SUSTRAIL demonstrator vehicle was tested at AFER's Railway Testing Center at Faurei, Romania. The vehicle is a flatbed freight wagon with modified Y25 bogies and a new wagon body structure, incorporating a number of design elements studied and/or developed during SUSTRAIL. These include:

- double Lenoir links
- a new linkage to increase transverse suspension stiffness
- special protective coatings on the wheelset axles
- disc brakes
- the use of high-strength steels for light-weighting the wagon body

The aim of SUSTRAIL has been to develop novel, sustainable technologies for freight vehicles 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. More specifically, the aim has been to develop a freight vehicle to meet a dual purpose:

- operation at 140 km/h, but limited to an axle load of 17–20 tonnes
- operation with an increased axle load of 25 tonnes, but limited to 100 km/h

During the testing of the SUSTRAIL demonstrator vehicle in May, 2015, the vehicle was operated safely at 140 km/h with an axle load of 21.5 tonnes, and achieved 145 km/h with an axle load of 17 tonnes. (Higher speeds may have been possible; the limiting factor in the testing was the locomotive.)

Therefore, the first of SUSTRAIL's aims has been achieved, while the second remains untested. Extensive testing is still needed before the vehicle can be homologated for railway use.

Elsewhere, the infrastructure innovations considered in SUSTRAIL have resulted in a mix of modelling techniques, rig/lab testing and trackside evaluation to assess their effectiveness. The innovations selected for trackside demonstration include:

- Premium Rail Steel
- Sensor Embedded Geo-textiles
- Under Sleeper Pads
- Wayside Monitoring

The main findings and conclusions are presented here.

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1. Introduction

SUSTRAIL aims to increase network capacity to enable higher delivered tonnage of freight, partly through the development of novel, sustainable technologies for freight vehicles 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 have been implemented in a demonstrator vehicle that has been tested at AFER's Railway Testing Center at Faurei, Romania, in May, 2015. This has a large 13.7 km ring with a maximum speed of 200 km/h, curve radius 1800 m with 150 mm cant, and straight sections of 1000 m and 950 m.

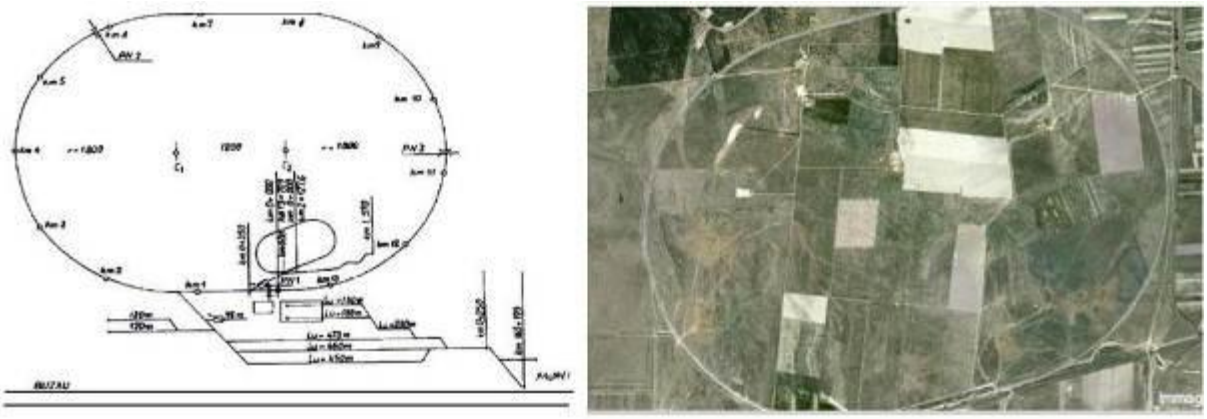


Figure 1.1 AFER's Railway Testing Center at Faurei, Romania.

Section 2 gives an overview of the SUSTRAIL vehicle and the testing and validation carried out as part of the SUSTRAIL's Demonstration activities. A ***Euronews*** team were on site for two days, and the report ("Getting rail freight back on track in Europe") can be seen on the web: http://www.euronews.com/2015/07/13/getting-rail-freight-back-on-track-in-europe/



Figure 1.2 SUSTRAIL wagon loaded with concrete sleepers.

In addition, this deliverable gives an overview of the infrastructure technology demonstration activities that SUSTRAIL has participated in.

- Because SUSTRAIL is looking to increase speeds and/or axle loads, the track will inevitably experience higher forces and stresses, and the rails will deteriorate faster. For improved operational safety and lower life cycle costs, the use of premium grade rail steels may be essential. Tata Steel's premium grade rail steel HP335 has been trialled at eight sites in the U.K., and Section 3.2 discusses recent findings.
- The impact on track substructure also needed to be considered. Section 3.3 discusses the measurement of embankment deterioration using sensor-embedded geotextiles. After taking measurements from a site near Chemnitz, Germany, SUSTRAIL can conclude that such sensors can be placed in track for several years and used as an effective long-term monitoring technology.
- The impact of under-sleeper pads (USPs) on switch and crossing deterioration has been studied at the Wooden Gates site in the U.K., and measurements of track stiffness for different pad types have been made and analysed. The effectiveness of USPs within the U.K. context is discussed in Section 3.4.
- The wayside monitoring technologies in place at the Luleå Railway Research Center (JVTC) facility in Sävast, approximately 30km north of Luleå on the Swedish iron ore line Malmbanan, have been studied. The importance of detecting wheel profile defects and faults in vehicle suspension, for operational safety as well as component life cycle costs, is discussed in Section 3.5.

2. Laboratory and Field Tests of the SUSTRAIL Vehicle

2.1 Demonstrator Vehicle

The SUSTRAIL vehicle's bogie is a modified Y25 bogie. The four modifications selected for the demonstration vehicle (highlighted in Figure 2.1) are:

- Double Lenoir links
- Longitudinal/axial arms
- Disc brakes – with electronic control and wheel-slide protection
- Wheelsets with coated axles

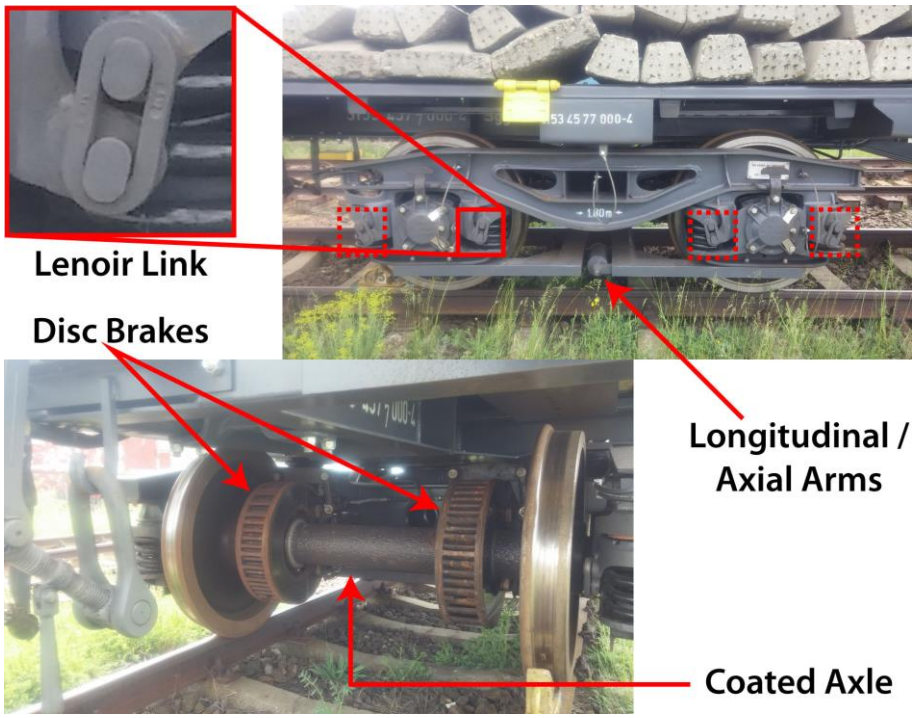


Figure 2.1 SUSTRAIL bogie – Y25 with modifications.

Various existing bogie designs use a single Lenoir link. The use of two Lenoir links (one either side of each axle box) can improve steering and reduce wheel wear, but it is known to cause unstable running behaviour. SUSTRAIL partners have run dynamic simulations of Y25 bogies modified with double Lenoir links in order to optimise the design and determine the requirements for suspension linkage between the wheelsets to improve stability. This analysis led to the longitudinal/axial arms that connect the wheelsets below the level of the axle boxes in Figure 2.1.

The modified suspension is expected to provide greater stability at higher speeds than the standard Y25 suspension, as well as improved curving behaviour and a reduction in wheel maintenance costs. For safe operation at higher speeds, the braking system needs to be redesigned to handle the greater forces and energy; increasing speed from 120 km/h to 140 km/h results in a 36% increase in the kinetic energy of the vehicle, and this additional energy is lost as extra heat during braking, i.e., potentially higher temperatures. In the case of tread brakes, this results in significantly increased damage to the wheels. The use of disc brakes not only protects the wheels, it reduces noise levels significantly during braking – and, since the wheel treads are generally in better condition, it reduces noise levels during normal running.

The protective coating on the axle is intended to prevent corrosion and to prevent damage to the axle from flying ballast stones, and thereby reduce the risk of cracks initiating at the damaged surface of the axle. This is expected to improve operational safety and reduce the maintenance needs and associated costs of the axle inspection and maintenance.

However, switching from tread brakes to disc brakes increases the total mass of the bogie, and more importantly the *unsprung* mass. This has the effect of increasing impact forces in the wheel-rail contact. To mitigate this, SUSTRAIL has investigated various methods for lightweighting the wagon structure, and for the demonstrator vehicle elements of the wagon structure have been manufactured from high-strength steel.

Finally, WiFi-enabled temperature sensors and accelerometers were fitted to the axle box, bogie and wagon to test new remote monitoring technologies.



Figure 2.2 SUSTRAIL wagon frame.

2.2 Testing and Validation

The testing activities carried out on the SUSTRAIL demonstrator vehicle at the Railway Testing Center in Faurei, Romania, during May, 2015, included the following:

- Laboratory (static) tests on the vehicle prior to field-testing.
  - Measurement of the load on each wheel to check for vehicle balance.
  - Tilting the vehicle to assess safe response to cant and curves (see Figure 2.3).
  - Brake tests – air pressure in the cylinder, and thrust forces acting on the blocks.
- Field (dynamic) tests to determine the running behaviour of the wagon.
  - Brake tests – stopping distance, up to 140 km/h with 17 tonne axle load (68 tonnes total).
  - Running safety to determine maximum accelerations of bogie and wagon.
  - Noise tests – pass-by noise only.
- Strain analysis of the wagon to check for plastic deformation damage.
  - Dynamic analysis to determine stresses and to assess structural safety, up to 140 km/h with 21.5 tonne axle load (86 tonnes total).
- Testing of vehicle monitoring technologies.
  - Temperature sensor on the axle box for condition monitoring.
  - Precision accelerometer on the bogie for monitoring dynamic response.
  - Low-cost accelerometers on bogie and wagon, and on track, for monitoring dynamic response.



Figure 2.3 Wheels lifted to simulate cant, for measurement of the coefficient of flexibility.

Vehicle testing at Faurei Railway Testing Center led to the following results and conclusions:

- The wheel load ratios on each axle indicated that the unloaded wagon was out of balance (by more than the usual 5% limit) and that the suspension needed adjustment. However, once loaded to 68 t, the ratios were within the limit.
- Measurements of the coefficient of flexibility indicate that the wagon should have good behaviour in canted curves, up to a superelevation of 150 mm, and that there is not a risk of derailment.
- In static brake tests, the filling and draining times of the braking system were not always within required limits, and the braking system efficiency was below the required minimum.
- In dynamic brake tests, the calculated brake weight percentage was within the limits for most test cases; additional testing is required at all loads and speeds for a clearer assessment of braking performance.
- Measured accelerations indicate that the wagon running behaviour is safe and satisfactory, although further analysis is required to determine ride quality.
- The measured pass-by noise satisfies the requirements of current noise standards.
- No permanent deformation of the wagon structure was found after dynamic testing.

Although some adjustments to the braking system and suspension will be necessary to bring the vehicle within required limits, the SUSTRAIL demonstrator vehicle was able to run safely at 140 km/h with 21.5 tonne axle load, thus meeting one of the project's twin aims for new freight vehicle design.

Whether the second aim (25 tonne axle load at lower speeds) has been achieved is less clear and further testing and analysis is required to establish the safe operational limits. The lightweight wagon structure is less rigid than a standard wagon structure and therefore the deflection under load is greater; at certain moments during the tests, oscillations of the wagon bed are clearly visible.

The various sensors connected to the bogie and wagon, and to the rails, operated without any connectivity problems or hardware faults. Only a preliminary analysis has been conducted to date. Regardless of the eventual findings, the devices will need to be tested on other vehicles, and ideally vehicles exhibiting a range of known faults to provide a clear reference for detecting and identifying early- as well as late-stage defects.

3. Performance analysis of infrastructure upgrades

3.1 Overview of Work Package 4 "Infrastructure"

This section details the trackside test work undertaken in support of the infrastructure innovations developed within the project. The innovations developed within Work Package 4 are detailed in Deliverables D4.1, D4.2, D4.3, D4.4 and D4.5; further implementation information is also included in Deliverable D5.4.

The objective of Work Package 4 was to study novel and sustainable technologies to enable the railway infrastructure to accommodate more traffic, whilst at the same time reducing deterioration of track and wheels through increasing the resistance of the track to the loads imposed on it by vehicles.

The work package comprised five tasks:

4.1 Performance based design principles for resilient track – To determine the factors that influence the resistance of track to the loads imposed, and how this can be improved.

4.2 Supportive ballast and substrate – The support condition vital to maintaining track geometry.

4.3 Optimised track systems and geometry – Track geometry measures and intervention levels.

4.4 Switches and crossings – Novel S&C component design, building on the outputs from INNOTRACK.

4.5 Track-based monitoring and limits for imposed loads – This includes the definition of Minimum Action Rules.

The infrastructure duty requirements were determined from Work Package 2 and, following consultation with the Infrastructure Managers, an FMEA was developed within Task 4.3 to identify the innovations for further development in SUSTRAIL. These innovations have been assessed via a mix of modelling techniques, rig/laboratory testing and trackside evaluation to assess their effectiveness.

The infrastructure innovations selected for trackside demonstration in Work Package 6 include:

- Premium Rail Steel
- Sensor-Embedded Geotextiles
- Under Sleeper Pads
- Track Based Monitoring

Table 1 has a summary of the innovations considered in Work Package 4.

Detailed reporting of the trackside demonstration is given in the following deliverables:

D6.2 "Summary of Infrastructure Upgrade and Testing," which considers the innovations to be validated trackside and looks at the test methodology;

D6.4 "Field Assessment and Performance Benchmark of Key Infrastructure Components," which summarises the infrastructure innovation testing that has been undertaken trackside within the project.

The main test results and overall conclusions are presented below.

Table 1 Infrastructure innovations.

Who	What	Task	Innovation	Which activity	Demonstrator for WP6
TATA STEEL	Premium rail steel	4.1 4.3	Premium rail steel	DATA + demonstrator	YES
USFD	Rolling Contact Fatigue	4.1	Improved predictions of RCF damage	Modelling	NO
USFD	Rolling contact fatigue – computer modelling for the different times to initiate RCF damage	4.1	Roller hardening	simulations	NO
UNEW	Testing and analysis of welds in CWR; novel materials, technologies, etc. (with Tata) Ultrasonic testing (lab conditions on rail samples) and analysis of results - on welds and Survey of existing inspection and monitoring technologies (with MerMec).other failure areas.	4.3 4.5	Specifications/ recommendations/ guidelines for novel steels, welding processes, technologies, etc.	Specifications/ Guidelines	NO
UNEW	Impact of profile/inclination on RCF (Romanian profile measurement at/with AFER). Potential work: Ultrasonic testing (lab conditions on various rail samples) and analysis of results. Survey of existing inspection and monitoring technologies (with MerMec).	4.3 4.5	specifications/ recommendations for new geometries or combinations (profiles, inclination, etc.), novel steel degradation, etc.	Specifications/ Guidelines	NO
LTU	Wheel profile measurements for track RCF estimation	4.1 4.3	Dynamic access charges	software	NO
TRAIN	Analysis of multifunctional sensorized geotextiles for subgrade and embankment reinforcement and monitoring	4.2	Multifunctional sensorized geotextiles for subgrade and embankment reinforcing and monitoring	Simulation + demonstration	YES
DAMILL MERMEC	Force information from the WID systems in Sweden and produce statistics on typical load spectra (vertical+lateral) from different trains.	4.5	Understanding what the potential is of extending track life by pinpointing and removing bad vehicles from operation.	Data analysis Demonstration	YES

Who	What	Task	Innovation	Which activity	Demonstrator for WP6
KTH	Geometry degradation	4.1 4.3	Optimized maintenance scheduling using novel methods for degradation prediction	Modelling	NO
HUD	Numerical modelling of the vehicle-track dynamic interaction at crossing.	4.4	Guidelines on parameters variation on wheel, track geometry, wing/crossing shape and support conditions	Modelling	NO
USFD	Test various lubricants under representative loading conditions	4.4	Improved lubrication regime for slide plates under switch rails	Laboratory	NO
HUD	Dynamic smart washer - Instrumentation of complex systems (Switches) whilst in operation and with a wide range of dynamic loading – algorithms for railways	4.4 4.5	Dynamic Smart Washer that allows (through data analysis) adapting condition evaluation of complex system such as switches	Laboratory	NO
NR	Evaluation of Under Sleeper Pads	4.4	Understanding the effects of Under Sleeper Pads on track stiffness and components	Demonstration	YES

3.2 Premium Grade Rail Steel

Tata Steel has conducted a research programme into understanding the fundamental metallurgical factors that affect the life of rails, drawing on the experience of destructive examination of RCF samples, site monitoring, laboratory testing and specialist metallographic examination such as EBSD. The key output of this research was to develop a range of innovative steel grades that were specifically aimed at increasing the wear and rolling contact fatigue (RCF) resistance of rail.

Eight trial sites around the United Kingdom have been selected to demonstrate the superior properties of Tata Steel premium grade rail steel HP335. Seven of these trial sites have been installed into Network Rail infrastructure, and the final site on a light rail system. The sites have been selected based upon their previous degradation history, and include a range of primary defect categories, curve radii and maximum line speeds. For the trial sites installed on Network Rail infrastructure there are three degradation mechanisms that are of concern: wear, plastic deformation and fatigue.

The trial sites were monitored both before and after the new rail installation, and historic maintenance information for the sites was shared to get a good baseline of standard-grade rail performance. There was regular site monitoring with teams from both Tata Steel and Network Rail, and the sharing of all the information gathered ensured transparency of the material performance.

Hett Mill is a site that historically has suffered from high-rail head checks (a form of Rolling Contact Fatigue) with the low rail showing little damage. With a standard R260 grade rail installation, the site typically developed head checks that had propagated into the severe category (<30mm) within 8-12 months of installation. The R260 pre-installation photograph (Figure 3.1) was taken approximately five months post grinding. The other photographs show the premium rail steel in service.

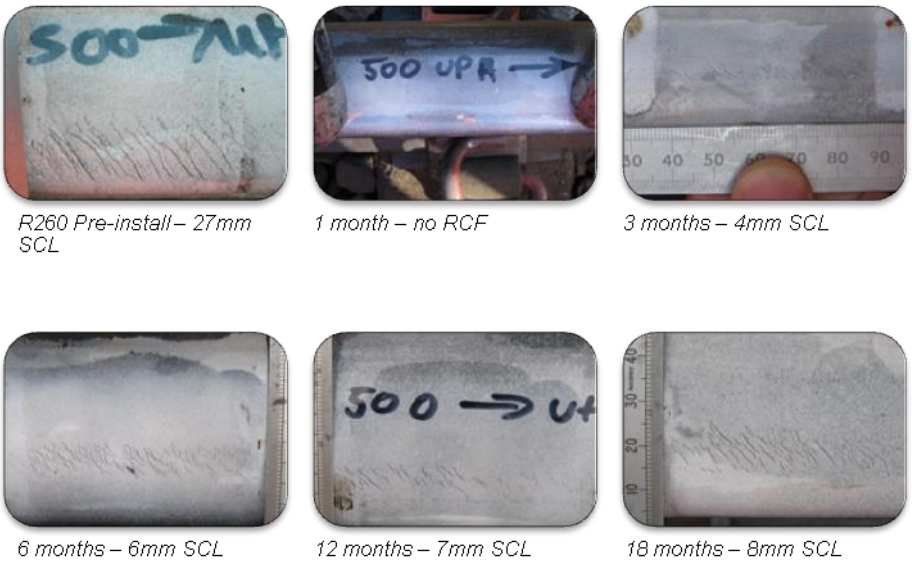


Figure 3.1 Visual inspection of surface crack length (SCL) at Hett Mill.

3.2.1 Premium Grade Rail Steel Summary

Projections for life cycle costs on one site were made after one year of data had been collected, and revised after four years. The two results were found to be within 1% of each other, giving confidence in the projected cost savings that were achievable. Over a period of five years, and using four years of monitoring information, the rail management costs (rail purchase, installation, inspection and grinding) on one site were reduced by 52%. Rail life spans were commonly doubled from that of previous rails whilst reduction in grinding by a factor of three was observed on some sites. From the vast quantities of site monitoring data, where HP335 rails had accumulated over 700 million tonnes of traffic, there were clear improvements in performance for every major rail degradation mechanism. Wear rates were greatly reduced, RCF growth was slowed, plastic flow reduced, spalling of low rails avoided and, last but not least, corrugation growth rates halved.

3.3 Sensor-Embedded Geotextiles

Increasing axle load and speed of freight vehicles causes a significant increase of the stress levels in the substructure. In the presence of soft subsoil it is important to quantify such effects and introduce strengthening and monitoring measures such as multifunctional geotextiles able to provide both strengthening and monitoring functions.

SUSTRAIL performed a field test at railroad near Chemnitz (Germany) that is characterised by very high traffic volume. An installation of sensor-embedded geotextiles was carried out in this area in 2007 in the framework of the EU project POLYTECT "Polyfunctional Technical Textiles against Natural Hazards". The sensor-embedded geotextile was installed in an embankment that was over 100 years old. Periodic measurements have been carried out in order to detect any movement within the embankment and study its evolution over time. Figure 3.2 shows an aerial view of the location of the test. The acquisition unit is shown in Figure 3.3.

The sensor was measured at different times in 2007, 2008, 2009 and 2010, and again in 2014 in the framework of the SUSTRAIL project. The test is extremely interesting since it proved the survivability of the sensors in service for many years with no negative influence of moisture on sensor fibres (there was no increase in optical attenuation observed).

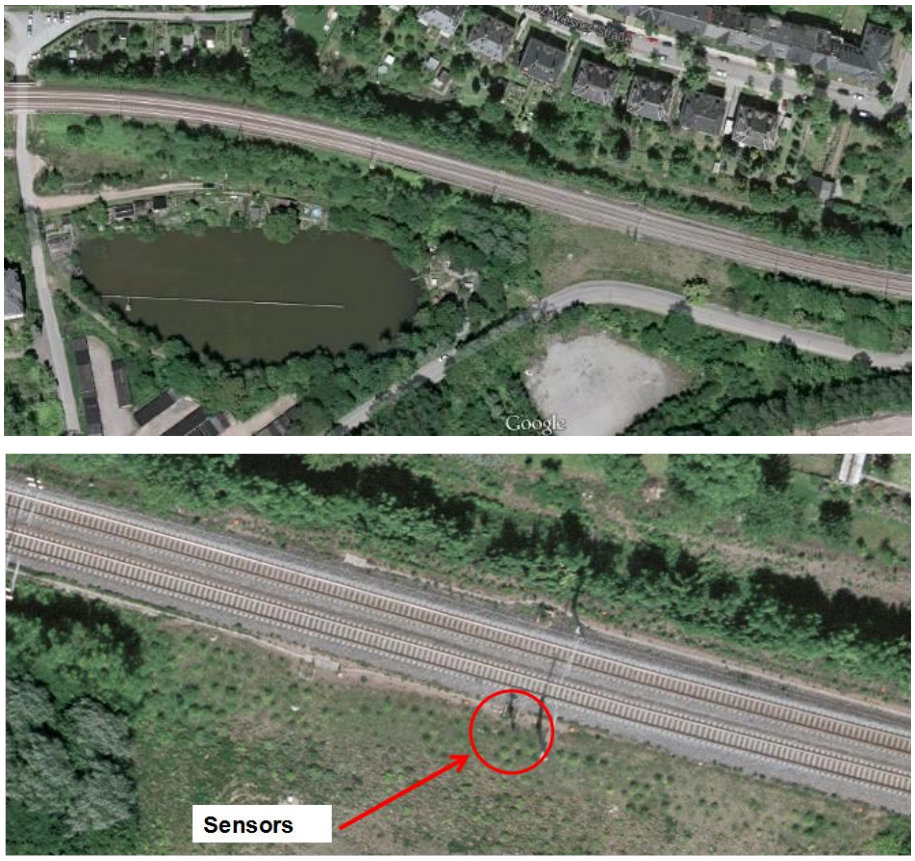


Figure 3.2 Test site of the multifunctional geotextiles to be tested in SUSTRAIL (Google Maps).



Figure 3.3 Sensor interrogation and data acquisition on the field.

3.3.1 Sensor-Embedded Geotextiles Summary

The installation of the sensor-embedded geogrids requires extra care over normal geogrids in order to prevent failure of the optical fibre (although the geogrid fabric provides some protection) and must be supervised by experienced technicians.

Permanent monitoring requires the availability of a reading unit, which is expensive (50–100k€), and associated permanent infrastructure (for the protection of the unit, the power supply, the data collection and transmission). Such a monitoring solution is therefore suggested only for critical infrastructures.

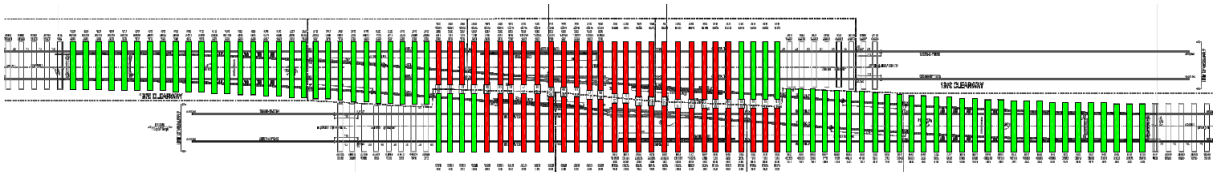
Periodic monitoring is a more economical solution, since the availability of the reading unit is required only for the few days needed to perform the acquisition of the sensors data. This solution is indicated for those structures for which a periodic monitoring is acceptable, or after the occurrence of a particular event.

3.4 Under-Sleeper Pads

Existing switches and crossings (S&C) without under-sleeper pads (USPs) require frequent maintenance to retain track quality. Track support (foundation) experiences accelerated degradation at S&C, and is particularly severe at the switch tips and crossing nose because of increased dynamic loading at the wheel contact transfer zones.

Degradation of the track foundation leads to void formation in the ballast below sleepers, and thus to additional failure modes, such as fatigue cracking, which is commonly found on cast manganese crossings. Voiding around the switch tips can also result in damage and failure of the switch's operating equipment and adjoining components.

The purpose of the investigation at the Wooden Gates site was to establish the impact, benefits or problems associated with the installation of under-sleeper pads. An Automatic Ballast Sampling (ABS) investigation examined the condition of the trackbed to determine the effectiveness of USPs. Wooden Gates (ECM7 33m 65ch) consists of two crossovers, one installed as a reference site (503A/B crossover) and the other containing USPs (502A/B crossover), as shown in Figure 3.4.



Switch Panel Under-bearer Pad Stifness, c_{stat}^{s} = 0.22 N/mm^3 *(Harder)*
Crossing Panel Under-bearer Pad Stifness, c_{stat}^{c} = 0.15 N/mm^3 *(Softer)*

Figure 3.4 Location of under-sleeper pads on 502A/B crossover at Wooden Gates.

Analysis of the Falling Weight Deflectometer results has led to the following conclusions:

- Pad type has a strong influence on D0 deflections, but does not impact on D300 or D1000 deflections with any statistical significance. This indicates that the pads provide system stiffness that depends on the pad type, and that the impact of this is independent of the impact of formation stiffness. See Figure 3.5.
- Pad type does not affect critical velocity of the trackbed, with wave propagation of the trackbed largely unaffected by the type of pad used. See Figure 3.6.
- For conventional track installed without pads, the subgrade stiffness has an influence upon the overall system stiffness. Where under-sleeper pads are installed, these have an influence on the overall system stiffness, reducing the impact of subgrade stiffness and generally improving the uniformity of system stiffness. This is especially true where the thicker Type 2 pads were installed. See Figure 3.7.
- The use of under-sleeper pads reduces the standard deviation of deflections of all trackbed layers, providing greater uniformity, and ultimately improved system stiffness control. See Table 2.
- Under-sleeper pad Type 2 is considered too soft for application in standard U.K. track without very stiff formation / subgrade. The levels of deflection observed were considered too great to provide good, maintainable track quality. The use of under-sleeper pad Type 2 would, however, be good for application over shallow

underbridges where shallow, stiff layers are present. Application of Pad Type 2 over UB102, where deflections were found to be very low, would provide improvements to rates of ballast breakdown and ballast settlement. Application of Pad Type 1 would likely provide greater benefit to application through S&C as a standard measure to improve uniformity of stiffness and reduce ballast strain / ballast breakdown.

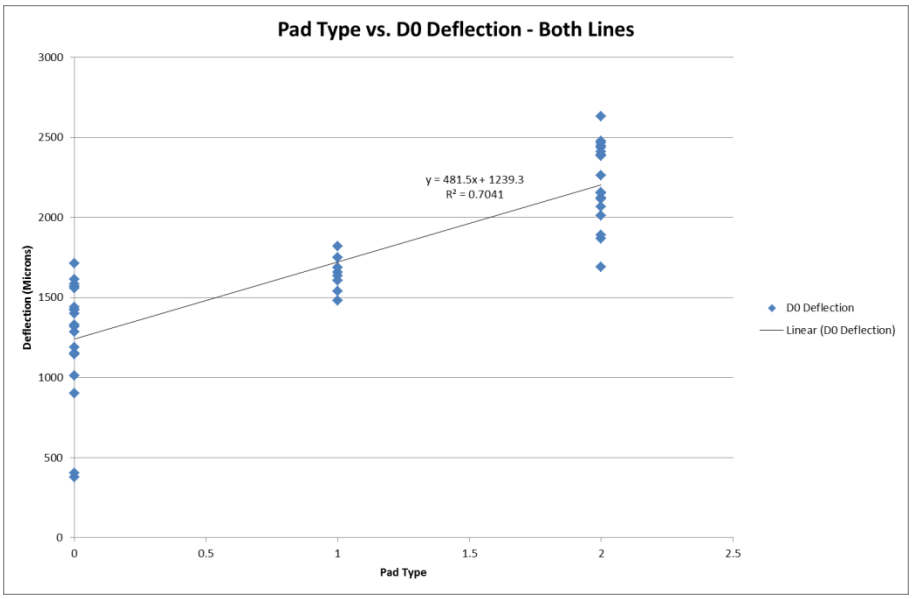


Figure 3.5 Falling Weight Deflectometer (FWD) results: Pad type vs D0 deflection.

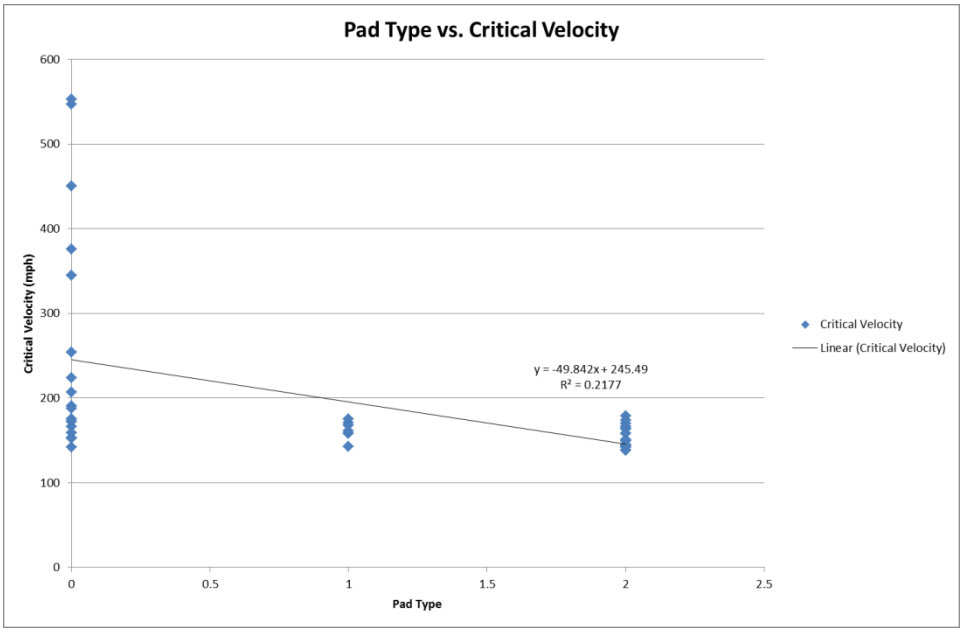


Figure 3.6 Falling Weight Deflectometer (FWD) Results: Pad type vs critical velocity.

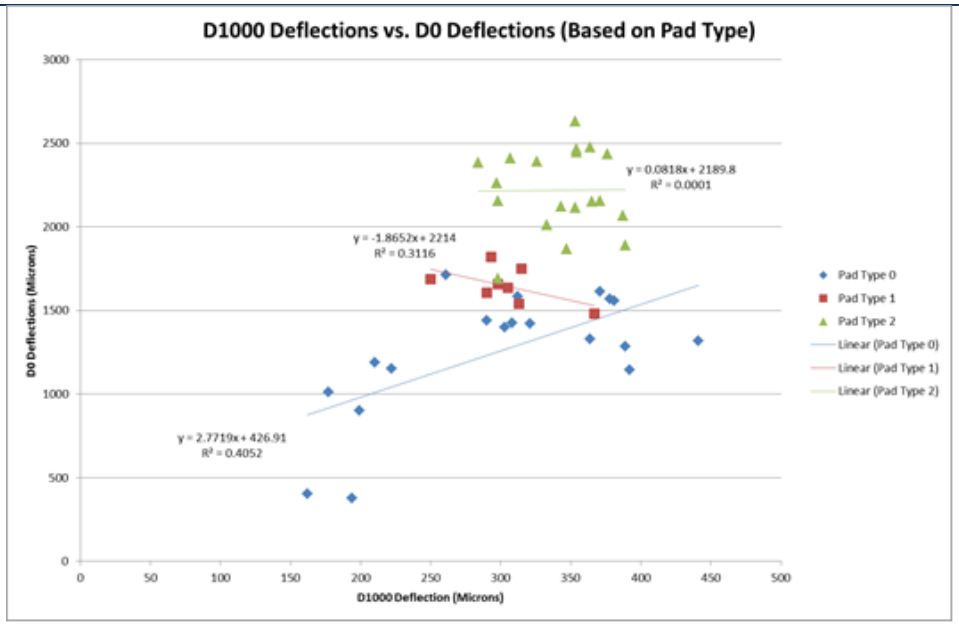


Figure 3.7 Falling Weight Deflectometer (FWD) Results: D1000 deflections vs D0 deflections (based on pad type).

Table 2 Standard deviation of deflections of all trackbed layers for different under-sleeper pad types at Wooden Gates.

	No USP - SD	Pad Type 1 - SD	Pad Type 2 - SD
D0 Deflections (Microns)	370.2	108.9	247.2
D300 Deflections (Microns)	252.1	67.1	131.7
D1000 Deflections (Microns)	85.0	32.6	32.2
Critical Velocity (Microns)	134.2	10.0	13.1

3.4.1 Under-Sleeper Pads Summary

While it is difficult to directly compare the 502A/B and 503A/B crossovers, owing to the different renewal types undertaken, there are definite trends and observations to be noted.

The ballast in 502A/B crossover does contain some evidence of breakdown owing to the passage of traffic and also due to tamping following / during the renewal. Through shakedown, the fines should be found in the bottom of the ballast and as a result, ballast appears dirtier at its base of the layer than towards sleeper bottom.

Generally, ballast is broken down through two major actions on the ballast. Firstly, tamping of the ballast crushes the ballast particles under the sleepers. Secondly, the ballast particles may become mobilised under ballast loading, resulting in ballast abrasion – wear of the ballast particles due to the particles rubbing together. Ballast tamping crushes the particles, whereas abrasion wears the particles. As a result, tamping results in “fines”, i.e., small gravel, which eventually breaks down further to sand-sized particles, whereas abrasion generates sand-sized particles from installation.

The relative absence of sand-sized particles in the lower ballast indicates that there is little abrasion occurring. This is likely to be the result of improved load distribution as a result of the pad, and also the “biting-in” effect of the pads, which further reduces ballast movement.

Further evidence of the positive influence of the under-sleeper pads is the relative lack of intermixing of the ballast with the underlying ash layer. In 503A/B, the ballast is extensively

intermixed with the ash layer, whereas in 502A/B, there is limited evidence of intermixing with the ash layer. Whilst this influence is, in part, due to the relatively young age of the ballast profile in 502A/B, it is also likely to be, in part, a result of the under-sleeper pads. The reduction in force brought about by the installation of under-sleeper pads will also reduce the dynamic stress at the formation interface, reducing capillary action and therefore mixing at the ballast formation interface.

Clearly under-sleeper pads can have a positive effect on the overall condition of the ballast, reducing ballast abrasion and dynamic forces at the ballast-formation interface.

3.5 Wayside Monitoring

The railway track is subject to loads imposed by passing vehicles. This causes high stresses and consequent deterioration of the track (and also the wheels), which reduces the life of components and increases life cycle costs. In order to accommodate more traffic, and at the same time ensure the required safety, imposed loads have to be measured and monitored.

Wayside monitoring systems are used primarily to inspect track loading by passing locomotives and wagons, but in general they monitor different train components and physical parameters, and can provide early identification of defects.

The test site was JVTC (Luleå Railway Research Center) facility in Sävast, approximately 30km north of Luleå on the Swedish iron ore line Malmbanan. The site was selected because the curve radius is quite narrow, inclination is low and at this location trains are normally running with constant speed without braking or heavy acceleration.



Figure 3.8 Monitoring station.

The wayside monitoring station accumulates data every day and in this report one typical month is presented: February, 2013.

During February, 2013, there was a total tonnage of 1,25MGT represented mainly by iron ore trains with 30 tonne axle load, heavy steel slabs transportation trains with 22-25 tonne axle load, other freight trains with 19-22 tonne axle load, passenger trains with a 13-17 tonne axle load and finally empty freight and iron ore trains with a 6-7 tonne axle load. The mean axle load during the month was 18 tonnes, with StD=21 tonnes, while the mean lateral force was 21kN, with StD=30kN.

The data is easier to interpret when split into different vehicle types. (The monitoring station has RFID readers that identify vehicles and vehicle types.)

Table 3 describes the potential defects, with descriptions of how the force-monitoring station can detect them. Detection does not necessary imply that the exact problem can be defined by the force data only, but the listed problem will generate a change in the force profile that can trigger further inspection of the specific vehicle.

Table 3 Vehicle defects that can be detected by the force measurement monitoring stations.

Defect	Sensors/parameter used for detection	Expected parameter reaction
Wheel out-of-roundness	Vertical forces along 3m of track	Sinusoidal variation
Wheel flat	Vertical forces along 3m of track	Short transients, repeated once/rev
RCF surface defect	Vertical forces along 3m of track	Vibration generated into rail
Worn wheel profiles	Lateral forces	Increased absolute magnitude
	Angle-of-attack (AoA)	Increased absolute magnitude
Suspension jamming	Vertical forces along 3m of track	Dynamic variation increased due to high unsprung mass
Increased friction in bogie centre bowl or side pads	Lateral forces	Increased absolute magnitude
	Angle-of-attack (AoA)	Increased absolute magnitude
Skew loading of wagon	Vertical forces	Non-symmetric wheel loads on loaded wagon
Broken suspension	Vertical forces	Non-symmetric wheel loads both on loaded and empty wagons
Skew/twisted wagon frame	Vertical forces	Non-symmetric wheel loads especially on empty wagons
Unstable operation (hunting)	Vertical forces along 10-30m of track	Sinusoidal variation left/right

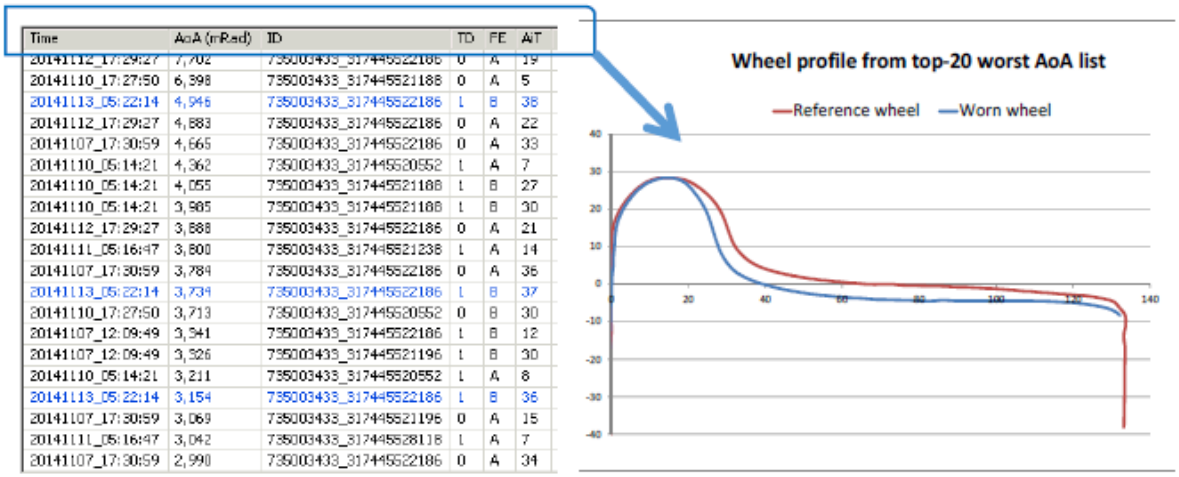


Figure 3.9 Webpage output from the StratoForce system. "Top-20" list of bad angle-of-attack (AoA) axles during the last 7-day period.

Based on Vehicle ID from the RFID tags, all data is grouped into vehicle owner lists. These lists represent a top-20 of bad vehicles for the selected car fleet. Figure 3.9 (left) gives an example from the monitoring station webpage where axle Number 19 in a specific train is at the top of the AoA-list.

The monitoring station is close to a wayside wheel profile measurement station, making it possible to check wheel profiles causing high lateral forces and/or high AoA. The wheel profile corresponding to Number 19 is shown in Figure 3.9 (right). There is no doubt that the axle with high AoA has worn wheels, although not in critical condition.

A frequent question about the force monitoring station is whether force measurement is really needed when wheel profiles can be measured by a parallel station. The answer is definitely "yes" since the wheel profile is measured only at one location on the wheel's circumference and there may be several defects not covered by the profile.

The lateral forces or AoA can be large without showing defect profiles, for example if the bogies have developed steering problems; the wheels may not yet be affected, but they will degrade fast. One typical example of this happened in the Sävast monitoring station when a newly repaired wagon had top score in the lateral force list. The wagon was taken to the workshop where it was found that it had badly adjusted side bearing pads (too thick). The yaw stiffness was very high.

There are many potential defects that can be indicated by measuring forces and angle-of attack on axles passing a wayside monitoring station. The effect is often indirect, making it difficult to give the exact status of the defective component or function, but for an overall overview of vehicles condition it is a really useful tool, maybe the best system currently available.

Working with forces requires some extra thinking by the analysis team as this is really proactive information. A newly overhauled axle or bogie can generate large forces and people tend to get suspicious about the relevancy. This happens, for example, in the case with thick side pads described earlier, or in winter climate when there is a heavy ice build-up in the bogie.

There have been studies by TTCI in the U.S. showing that 80% of the cases with large lateral forces in 3-piece bogies can be traced down to a root cause in jammed bogie steering. If such a bogie is kept in traffic, it will inevitably lead to reduced wheel life.

3.5.1 Wayside Monitoring Summary

There are many benefits in finding and removing vehicles with high track forces, most importantly the reduced risk of derailment but there are other factors to consider. The list presented in Table 4 is based on a combination of brain-storming and calculations.

Data from the monitoring station in Sävast gives typical values for different vehicles, but using them as general values to set limits for other sites is very difficult. Curve radius, cant, humidity, lubrication, rail profiles and train speed are all factors that influence the lateral forces. It is more appropriate to use the output in relative terms, and to adapt to each monitoring site. After installation of a new site, the traffic can be studied and individual alarms set for each vehicle type.

When lateral forces are to be measured, the station should be placed in a narrow curve that puts extra demand on the steering ability. The radius must, on the other hand, still be in a range where steering is possible. If it gets too narrow, the lateral force data will not tell about steering ability of the vehicles, but will instead be dominated by friction conditions and the rail profile at the site, i.e., local parameters.

Table 4 Benefits achieved when installing ALC monitoring stations.

Benefits from installing and using ALC monitoring systems

Strategy	Effect	Comment
Repair 5% of the axles and bogies with highest lateral forces	The mean lateral forces will drop 10% implying that also total rail and wheel wear will be 10% less.	Effect calculated by using data from the JVTC monitoring station and a simple friction work model
Repair 5% of the axles with highest dynamic vertical load	Very small effect as long as forces are below safety limit.	Effect calculated by using data from the JVTC monitoring station
Invest in 120 more ALC stations in Europe	Reduced risk of derailment. The Benefit/Cost ratio is 7,80 over 30 years	Effect according to the D-rail project D7.4, ref [4].
Increase the number of force monitoring stations (e.g. ALC)	By reducing the distance between stations, the downtime due to track inspection after defect vehicles (e.g.wheel flats) will be reduced. A simple model would be to assume proportional reduction in downtime.	Budget price according to D-rail D7.4 is €110000 per ALC-station. Based on data from Sweden, a 30km track segment might take more than 60 minutes to check after a severe wheel flat has passed. On single track lines, all traffic is blocked during that time.

4. Conclusions

Not all the innovations examined within SUSTRAIL could be included with the Demonstration activities of Work Package 6, which has focussed on large-scale field tests. Details of all the innovations considered are presented in the deliverable reports for Work Packages 3 (Vehicle) and 4 (Infrastructure).

4.1 Vehicle

During May 2015, a SUSTRAIL demonstrator vehicle was tested at AFER's Railway Testing Center at Faurei, Romania. The vehicle is a flatbed freight wagon with modified Y25 bogies and a new wagon body structure, incorporating a number of design elements studied and/or developed during SUSTRAIL. These include:

- double Lenoir links
- a new linkage to increase transverse suspension stiffness
- special protective coatings on the wheelset axles
- disc brakes
- the use of high-strength steels for light-weighting the wagon body

The aim of SUSTRAIL has been to develop novel, sustainable technologies for freight vehicles 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. More specifically, the aim has been to develop a freight vehicle to meet a dual purpose:

- operation at 140 km/h, but limited to an axle load of 17–20 tonnes
- operation with an increased axle load of 25 tonnes, but limited to 100 km/h

During the testing of the SUSTRAIL demonstrator vehicle in May, 2015, the vehicle was operated safely at 140 km/h with an axle load of 21.5 tonnes, and achieved 145 km/h with an axle load of 17 tonnes. (Higher speeds may have been possible; the limiting factor in the testing was the locomotive.)

Therefore, the first of SUSTRAIL's aims has been achieved, while the second remains untested. Extensive testing is still needed before the vehicle can be homologated for railway use.

4.2 Infrastructure

The infrastructure innovations presented in this deliverable cover rail resilience, earthworks, track bed support and vehicle monitoring for damage prevention and therefore neatly cover the main drivers for infrastructure resilience within the SUSTRAIL project. They have all been successfully tested trackside within an operational rail environment at sites in the United Kingdom, Germany and Sweden and proved to be viable innovations to be taken into use on the railway system.

The barriers to their implementation are fully discussed in Deliverable D5.4, but they can all be considered suitable for future adoption onto the railways of Europe once they are fully developed and approved for use.

References

Deliverable D5.4, “Technical Implementation and Phasing Issues.”

Deliverable D6.2 “Summary of Infrastructure Upgrade and Testing,” for an introduction to the Infrastructure upgrades identified for trackside trials.

Deliverable D6.4, “Field Assessment and Performance Benchmark of Key Infrastructure Components,” which summarises the infrastructure innovation testing that has been undertaken trackside within the project.