



THE SUSTAINABLE FREIGHT RAILWAY: DESIGNING
THE FREIGHT VEHICLE – TRACK SYSTEM FOR
HIGHER DELIVERED TONNAGE WITH IMPROVED
AVAILABILITY AT REDUCED COST

Concluding Technical Report

Edited by Adam Beagles



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SUSTRAIL

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

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FRONT MATERIAL

INTRODUCTION AND EDITOR'S NOTE

The aim of the SUSTRAIL project was “*to contribute to the rail freight system to allow it to regain position and market*”. To achieve this, a consortium of European experts was formed and considered combined improvements in both freight vehicle and track components in a holistic approach including economic assessments. Achieving a higher reliability and increased performance of the rail freight system as a whole contributes to an increased profitability for all stakeholders making rail freight more attractive. This final report provides a summary of work that occupied almost 70 person-years.

This four-year project produced 36 reports (deliverables), the largest having more than 200 pages (details in Appendix 2). There are no references in this work; the relevant deliverables are indicated for specific sections and these should be consulted. Most of the reports are publically available so the reader is encouraged to consult them via the deliverables page of the website: www.sustrail.eu. Publications arising from the project have appeared in academic and trade literature; Appendix 3 contains a partial list.

Quotations at the beginnings of chapters are from the SUSTRAIL “Description of Work”, Annex 1 of the project’s grant agreement..

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EXECUTIVE SUMMARY





1. EXECUTIVE SUMMARY

SUSTRAIL is the acronym for the EU Framework 7 collaborative research project with grant number 265740. It addressed theme SST.2010.5.2-2: “The sustainable freight railway: Designing the freight vehicle – track system for higher delivered tonnage with improved availability at reduced cost”. In the context of strong growth in road transport and a forecast growth in volumes of freight its aim was to contribute to the rail freight system to allow it to regain position and market, aligned with a target of the European Commission. The project was undertaken by a balanced consortium of infrastructure managers (IMs), freight operators, companies involved in the rail sector, and academics.

SUSTRAIL considered a combined improvement in both freight vehicles (with a targeted increase in speed) and track components (for higher reliability and reduced

maintenance), and also the interactions between them. A holistic approach was adopted; benefits to freight and passenger users (since mixed routes were considered) were quantified through the development of appropriate business cases to ensure profitability for all stakeholders. The background, motivation and approach of the project are presented in more detail in **Chapter 2**.

Chapter 3 defines the context into which the SUSTRAIL innovations would be introduced. It briefly discusses the regulatory framework that any innovations in track or vehicle should comply with, particularly the six Technical Standards for Interoperability (TSI) relevant to the SUSTRAIL project and the UIC leaflets on standard construction measures and operating procedures. Also, due to the diversity of the European rail freight industry, thorough benchmarking studies were carried out at three

diverse freight systems, operating on routes in Spain, Bulgaria, and the UK. The final section of this chapter summarises the future logistics requirements for freight on these three routes.

Chapter 4 presents the business case for the SUSTRAIL project. It was integrated into the project early on, with duty requirements defining what the rail industry needs and would benefit from (in terms of technical innovations in the vehicle and track) to meet the overall objective of increasing the traffic and market share of rail freight. The key technical innovations proposed within the project were assessed using: LCC (Life Cycle Cost), RAMS (Reliability, Availability, Maintainability, and Safety), and cost benefit analyses.

The duty requirements included: increasing freight operating speeds, reducing energy use, and reducing forces causing damage to the track. Other factors were also taken into account such as improved aerodynamics, environmental noise mitigation and easy integration with the existing fleet, maintenance procedures, and safety standards. The cost-benefit analysis included financial analysis of the impact on IMs, train operators, end users, and government and a socio-economic cost-benefit analysis covering all parties.

Since innovations cannot be considered truly useful if they are not implemented, it was also important to consider potential barriers to their implementation and demonstrate reasons to adopt them; part of this was considering the financial interface between IMs and freight operators.

‘Rolling stock innovations’ (Chapter 5) presents the work to improve vehicle design resulting in reduced operating costs for both vehicle and track, and reduced environmental impact. One of the main rolling stock innovations developed as part of the project was the SUSTRAIL freight bogie (patent pending). This was based on the established Y25 type bogie and incorporated the following innovative technologies:

- Double ‘Lenoir link’ primary suspension to improve the curving properties of the system and reduce damage to the track
- Interconnecting links providing lateral stiffness between the axle boxes (to improve running behaviour and reduce wheel wear)
- Noise reduction technologies: brake discs, and spring inserts
- Braking system: brake discs, redundant pneumatic back-up system, wheel-slide protection
- Condition Monitoring: weighing valves installed in the bogie for local load monitoring; electro-pneumatic braking control with diagnostic functionality; thermocouple and accelerometers on each axle box
- Power Supply: bearing generator with battery back-up and intelligent power management
- Reduced weight: use of high strength steels, and optimised section designs
- Protective axle coating: to reduce the potential for fatigue cracks initiated by surface damage

Computer simulations were used to assess various combinations of the technology improvements and to establish critical speeds and optimal design parameters for the new primary suspension system. Other analyses and tests were carried out as appropriate: e.g. both ballistic tests and non-destructive tests were carried out on axles with and without the coating; finite element analysis of the bogie.

Regarding the vehicle structure, the project aimed to develop an adaptable, intermodal flat wagon, addressing three main design criteria: lightweight; increased capacity; and sustainable, low-cost solutions (including recycled materials and interchangeable components). The vehicle body used novel high strength steel grades and cold formed profiles, optimised spigot disposition, sustainable flooring materials, and lightweight covers.

Other innovations that did not feature on the vehicle were studied as ‘virtual demonstrators’. These included:

- Measures for reducing aerodynamic drag including logistics aspects of loading
- Options for locomotive traction
- Friction control: recognised to reduce environmental pollution, vibration, noise, and the cost of operation and maintenance; tests were carried out on the effect of friction modifiers in the contact zones of both wheel and rail, and wheel and brake shoes.
- Monitoring the structural integrity of axles (using low-frequency vibrations and acoustic emissions).
- Energy harvesting systems for powering condition monitoring equipment

‘Infrastructure Innovations’ are presented in **Chapter 6**. This part of the project aimed to improve the resilience of the infrastructure system, reduce costs, and improve track accessibility. There was a strong link between this work and the vehicle work described in Chapter 5 since the vehicle design directly affects track deterioration and vice versa. The work considered many aspects of infrastructure: rail, support (including ballast, transitions, and reinforcements), switches and crossings, and wayside condition monitoring. Innovations were selected by the infrastructure managers using a ‘failure modes and effects analysis’ (FMEA). Following this, a wide range of testing and simulation work was undertaken to produce models, recommendations, and procedures.

A few highlights:

- development of ‘Minimum Action Rules’ for corroded rail
- mechanical testing of insulated joints
- the use of advanced rail materials to combat wear and rolling contact fatigue
- testing of lubricants for slide plates
- optimisation of the support stiffness in the area of the crossing panel (under-sleeper pads)
- optimising transitions
- vehicle defects that can be detected by dynamic force monitoring and associated maintenance limits

Chapter 7: Demonstration and validation.

The SUSTRAIL prototype vehicle has been built. Laboratory and track tests to establish the viability of the innovations it incorporates are described in this chapter.

As well as the SUSTRAIL prototype vehicle, four track innovations have been tested on mainline infrastructure:

- Premium rail steel
- Earthwork-stabilising geo-textiles with inbuilt monitoring sensors
- Under-sleeper pads
- Wayside monitoring of vehicles

These tests are described in this chapter. Other innovations included modelling approaches and monitoring equipment that could reduce uncertainties and result in more robust maintenance regimes for track, switches and crossings, and associated structures.

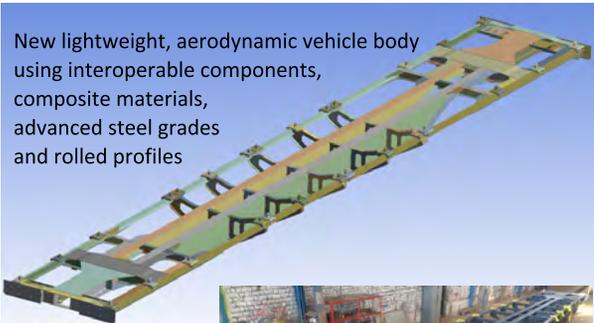
During four years the SUSTRAIL project occupied almost 70 person-years of effort and has delivered significant advances toward achieving a sustainable freight railway.

SUSTRAIL TECHNOLOGY



Optimisation of Lenoir link parameters

New bogie design with double Lenoir links and interconnecting links



New lightweight, aerodynamic vehicle body using interoperable components, composite materials, advanced steel grades and rolled profiles

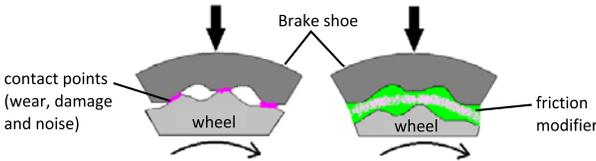


Freight Train of the Future

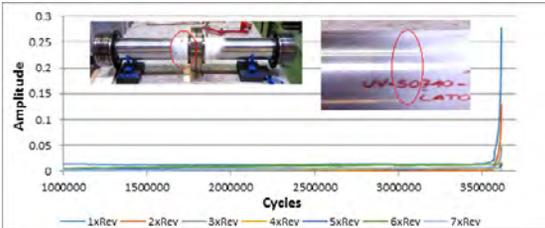
Advanced disc brake system to reduce noise, wear and damage



Use of new axle coating exhibiting improved corrosion resistance and crack initiation resistance in demonstration vehicle wheelsets

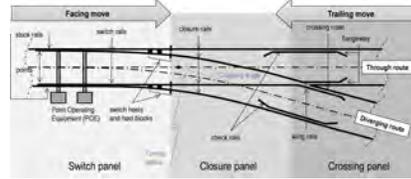
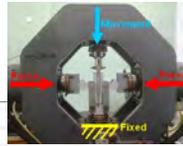
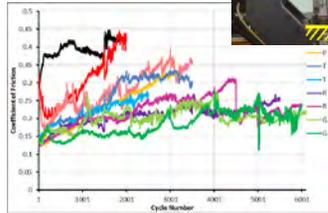


Testing of friction modifiers to optimise wheel brake contact and rail wheel contact



- On-board condition monitoring development:
- Axle monitoring using 'Acoustic Emission' and 'Low Frequency Vibration' (pictured)
 - Axle box temperature monitoring
 - Bogie acceleration monitoring

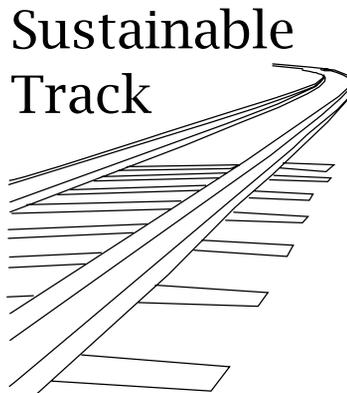
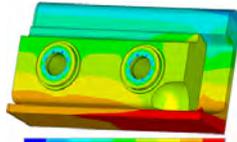
Testing and comparison of different lubricants for S&C



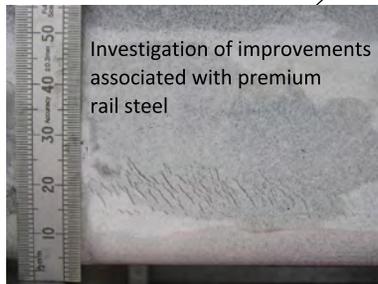
Optimisation of the operation, safety and reliability of Switches and Crossings (S&C)



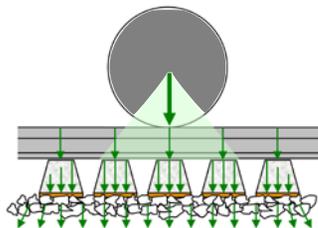
Track joint testing and numerical modelling



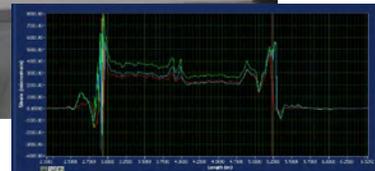
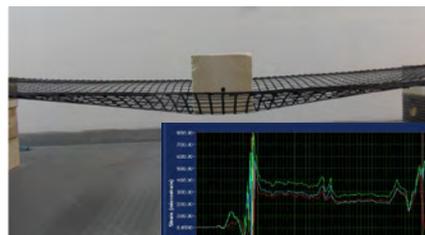
Wayside condition monitoring: Assessment and development of technologies for preventative and intervention-level maintenance strategies



Investigation of improvements associated with premium rail steel



Under Sleeper Pads enable more even wheel force distribution. Track tests were carried out to study effect of pad stiffness



Strain tests of geosynthetic fabrics for embankment reinforcement

SUSTRAIL: THE PROJECT



2. SUSTRAIL: THE PROJECT

SUSTRAIL is the acronym for “The sustainable freight railway: Designing the freight vehicle – track system for higher delivered tonnage with improved availability at reduced cost”. The SUSTRAIL proposal was submitted to the European Commission at the beginning of 2010 in response to the call FP7- SUSTAINABLE SURFACE TRANSPORT (SST)-2010-RTD-1, topic SST.2010.5.2-2; it was successful and was granted contract number 265740.

A strong multidisciplinary consortium of internationally recognized experts with a balanced combination of infrastructure managers, freight operators, and industry, including large and small enterprises, with support from academia; more than 30 beneficiaries, had been assembled to fulfil the project objectives; for details see Appendix 1.

Figure 2.1
Inspecting testing
facilities during kick-
off meeting



The project started officially with a kick-off meeting in June 2011 (see Figure 2.1). Consorzio TRAIN in Italy coordinated the project which had a total budget of approximately 9.3 Million Euro, an EU contribution of approximately 6.6 Million Euro. The project was to complete in May 2015 after almost 70 person-years of effort.

2.1 BACKGROUND AND MOTIVATIONS

Rail transport is unique in its complexity. It is the only transportation sector that must consider the vehicle, the transportation medium (e.g. the track), and the network (flows, regulations, procedures) in parallel. This is in contrast to air or water transport where apart from at termini (airports or ports) the aircraft or ship dominates the analysis, or to road transport, where the analysis of roads, highways, and bridges and the analysis of vehicles are undertaken independently. Rail transport is also unique in the diversity of operating procedures, codes, regulations, guidelines, and business models across EU member states. SUSTRAIL fully recognized the challenge of achieving meaningful change in the rail sector. It requires a broad-based consortium committed to concrete actions aligned toward a common outcome. This truth is reflected in the SUSTRAIL consortium, work-plan, exploitation, and management structure.

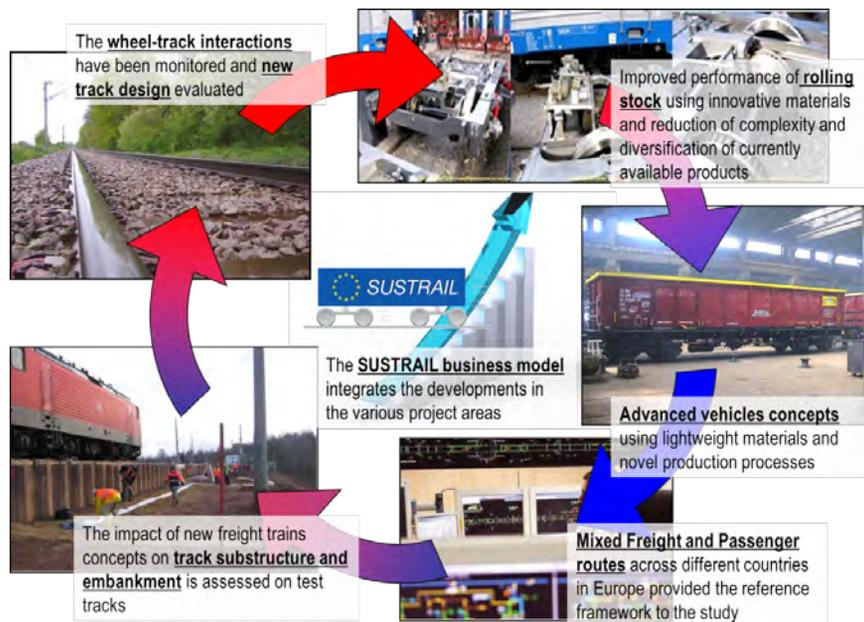
Change for the rail industry is necessary because of the continued and projected growth and productivity of Europe. Kilometres driven on Europe's highway networks generally doubled between 1980 and 2000, and is projected to double again by the year 2030. Especially in urban areas (where goods need to be delivered, and congestion is difficult), there is no space for additional highway networks, and highway area managers are attempting to reduce vehicle traffic. The result is that more freight and more passengers will have to travel by rail to meet Europe's short, medium, and long-term traffic needs.

Change is opportunistic because of advances in computational methodologies, design methods, high-performance materials (alloys, composites, and hybrids), sensors, and sensing technologies. As a whole and largely because of the complexities mentioned, the rail industry is lagging in its adoption of state-of-the-art techniques and technologies that are gaining traction in air, shipping, and road transport.

2.2 RATIONALE

The SUSTRAIL integrated approach is illustrated in Figure 2.2; this approach included innovations in rolling stock and freight vehicles combined with innovations in the track components. The benefits of these innovations to freight and passenger users (since mixed routes are considered) were quantified through the development of an appropriate business case with the estimation of cost savings on a life-cycle basis. A holistic approach to vehicle and track sustainability was taken, since improvements in track design and materials alone are not enough to meet the increasing demands on the rail system.

Figure 2.2
The SUSTRAIL
integrated approach



2.3 OBJECTIVES

SUSTRAIL had the objectives of increasing the sustainability, competitiveness, and availability of European railway networks. Because these words can mean different things to different people they are defined in Table 2.1.

Sustainability	Competitiveness	Availability
<i>The capacity to endure with respect to social, economic, and ecological considerations.</i>	<i>The ability to provide products and services more effectively and efficiently than competitors</i>	<i>Disruption-free access to railway freight and passenger traffic with optimal network flow</i>
<ul style="list-style-type: none"> » substituting car and truck traffic with rail passenger and freight traffic with their lower fuel consumption and emission production » designing vehicle and track systems in a life-cycle cost context » considering the environmental footprint when designing vehicle and track systems » employing lighter, more eco-friendly design materials 	<ul style="list-style-type: none"> » increasing the economic, travel-time, and ease of use aspects of the motivation for using rail transport instead of air, water, or road transport » implementation of performance-based design to increase the efficiency of rail vehicles and track systems » increasing vehicle speeds » increasing vehicle performance 	<ul style="list-style-type: none"> » sensor-enabled condition-based maintenance programs » reduction of the frequency of maintenance actions » reduction of maintenance and repair action times » improved operational procedures » standardisation and benchmarking of best practice

Table 2.1
Defining and achieving key SUSTRAIL parameters

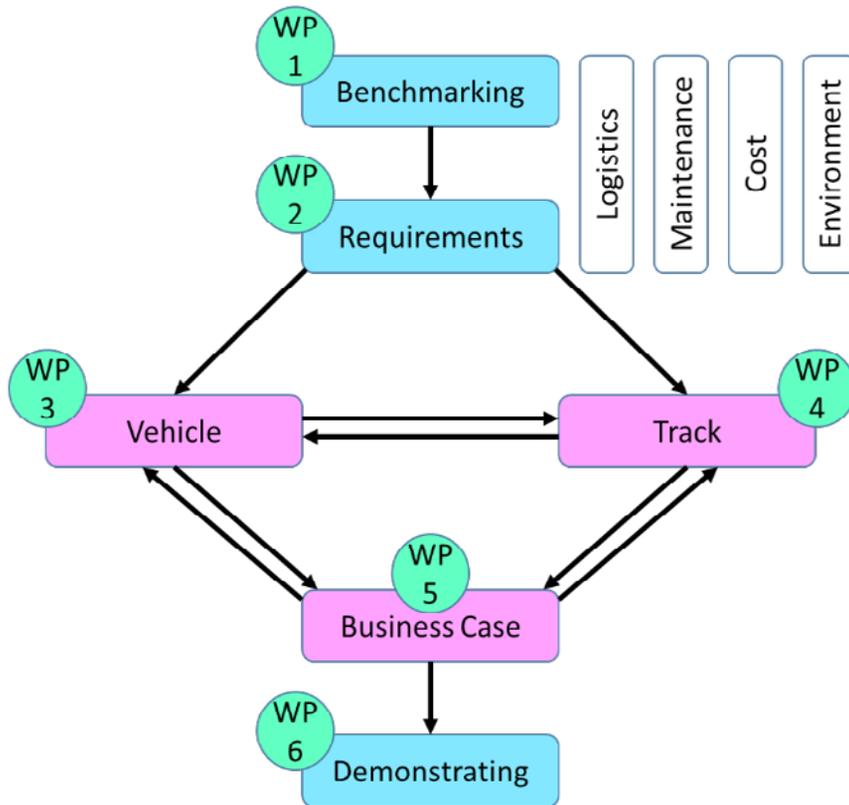
To progress in these three parameters SUSTRAIL considered:

- **Methodology:** a holistic approach that leverages the skills of the consortium was employed. Vehicles and their subcomponents, freight, passenger, track, and substructure, and operational procedures were included.
- **Implementation Timeframe:** a focus on developing both short-term and medium-term solutions as appropriate, for example, rail companies that have recently retrofitted vehicle systems at large expense are not receptive to new short-term vehicle requirements. SUSTRAIL balanced actions for short-term impact with room to be strikingly innovative for mid-term impact.
- **Means of Application:** integrating the different topic areas (vehicles, track, and operations) and demonstrating indications, constraints, and opportunities from four real routes offering geographic dispersion as well as differences in condition, and in speed, loading, and frequency of traffic.

2.4 STRUCTURE

The SUSTRAIL work-plan was designed to meet the project's objectives by integrating the diverse research areas, skills, and capabilities of the consortium in a logical evolution of workpackages (WPs) and tasks. Figure 2.3 indicates the principle interdependencies between the project components which are summarised in Table 2.2.

Figure 2.3
Overview of project
structure



WP	Name	Leader	Objective	Comments
1	Benchmarking	UNEW	To determine the 'zero' state, i.e. performance of the existing system	» 3 mixed traffic routes » AFER test track
2	Duty Requirements	NR	To determine the current and future requirements of the wider European system	» Future logistics requirements » Track design and vehicle performance requirements
3	Freight Train of the Future	HUD	To study freight vehicle components and identify low-cost modifications to enable higher capacity	» Vehicle component design to reduce track impact
4	Sustainable track	NR	To identify track design parameters that can be modified to reduce impact of freight traffic	» Performance-based design principles for resilience » Intelligent monitoring systems to reduce maintenance
5	Business Case	UNILEEDS	Cost-benefit analysis of proposed vehicle and track modifications using RAMS and LCC	» Benefit models and access charging » Technical implementation and phasing issues
6	Technology Demonstration	AFER	Demonstration of track and vehicle upgrades	» Vehicle and track testing at AFER test track » Telemetry of upgraded track and vehicle, and routes » Performance review
7	Dissemination and Exploitation	UIC	Workshops, conferences, training, guidelines, standards and promotional activities	» SUSTRAIL identity (artwork) and awareness activities » Exploitation strategy planning and risk analysis
8	Project Coordination	TRAIN	Administration, legal and financial issues	» Ensuring clear governance and communication » Administration coordination

Table 2.2
Workpackages (WP)

The first workpackage was to provide a benchmark of the current freight ‘system’ to establish the existing ‘zero state’ for subsequent comparative and enhancement activities. The second workpackage had the objective of defining duty requirements for vehicles and track to potentially double the life of track components when combined with low impact vehicles. These two workpackages set the scene for the next activities carried out in the three main research workpackages: WP3, WP4, and WP5.

WP3 was to come up with innovations for freight vehicles at different levels: an improved conventional vehicle using optimised existing technology and a ‘futuristic’ design utilising technology which had not yet been proven in the railway field but was considered to have great potential. New wheel profiles and improvements in suspension design for a mixed traffic railway were to be investigated. Also: traction and braking systems for high-speed low-impact freight operations; novel materials for lightweight high performance freight wagon body vehicles and bogie structures; and advanced condition based predictive maintenance tools for critical components of both railway vehicles and the track.

WP4 was to build on the duty requirements defined in WP2 and optimised track design and maintenance approaches were to be investigated to move towards the ‘zero maintenance requirement’ target.. Track failures were to be identified and prioritised to determine where to focus activities, in addition to a program of research that had already been proposed by the infrastructure managers in the consortium.

WP5 aimed to provide, on a qualitative and economical basis, the potential costs and benefits for end users of the proposed innovations. Recommendations for whole-system implementation, including phasing-in of novel technologies and strategies for the equitable redistribution of whole-system savings were to be studied. Techniques for assessing and targeting refinements of innovations were also included in this workpackage.

Validation of the project results and testing of a selection of the infrastructure and vehicle component upgrade solutions and technologies developed in the project were to be carried out in WP6. The practical demonstrations were designed to provide information for the analysis of the potential improvements in terms of system reliability (damage and failures, maintenance costs, etc.) and system performance and capabilities (speed, load, etc.). Practical demonstrations were to be carried out on the test route at the Romanian Railway Authority’s Railway Testing Centre.

2.5 APPROACH

For each innovation the aim was to move from fixed-term to performance-based maintenance. The main steps of reliability analysis are:

1. Select a target reliability level
2. Identify the significant failure modes of the structure
3. Decompose the failure modes in series of parallel systems of single components
4. Formulate failure functions (limit state functions) corresponding to each component in the failure modes
5. Identify the stochastic variables and the deterministic parameters in the failure functions
6. Estimate the reliability of each failure mode
7. In a design process, change the design if the reliabilities do not meet the target reliabilities
8. Evaluate the reliability result by performing sensitivity analyses

By adopting performance-based design methods the behaviour of a component/system across a certain time frame (life cycle) can be taken into account. This is fundamental for maintenance tasks. The analysis of the changes of a component/system across its lifetime allows the adoption of condition-based and predictive maintenance approaches whose aim is to minimize the need for unscheduled operations, thus lowering the number and impact of maintenance tasks. As an example, the workflow of the activities performed for track is depicted in the Figure 2.4.

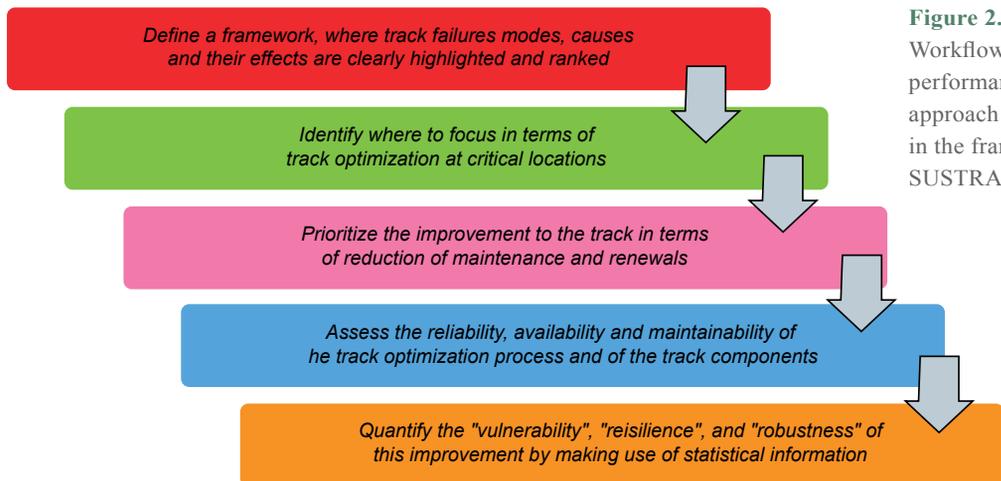
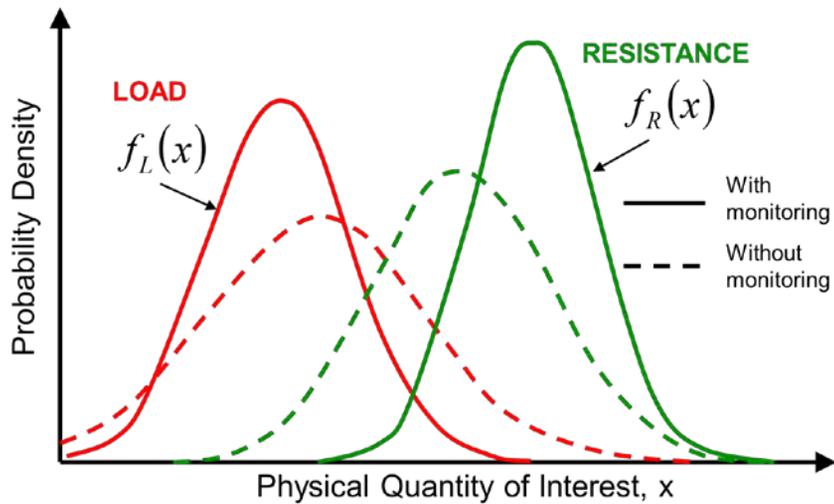


Figure 2.4
Workflow of performance-based approach activities in the framework of SUSTRAIL

The heart of the analysis is the construction of the probabilistic evaluation that an encountered load L may exceed a structure's ability to carry that load, (i.e. its resistance R), which is represented by the overlapping portion of the PDF curves of Figure 2.5. The probability that the load exceeds the structure's ability to carry that load is denoted P_{fail} . In first or second order reliability-based design methods P_{fail} is estimated via the calculation of a reliability index (β), the normalised distance between the origin of the state variable space (x) and the surface defined by the limit state function ($G(x)=R(x)-L(x)$) being zero. A more refined calculation of P_{fail} uses Monte Carlo methods, where the variables are assigned probability density functions and the solution is found by generating random simulations to determine the proportion that fail.

Figure 2.5

Gaussian distributions of random variables, with (full line) and without (dashed line) monitoring



2.6 EXPECTED BENEFITS

The SUSTRAIL approach, based on innovations in both rolling stock and track structures, was expected to impact on both infrastructure and vehicles, so the economic benefits should be found on both sides of the wheel/rail interface:

- A strong impact on system reliability through the definition of performance-based design principles for resilient tracks with higher reliability and targeted safety levels
- Significant economic savings by extending the life, durability, safety and reliability of railway infrastructures which, indirectly, will stimulate economic growth
- A reduction in whole life costs of the wagon by 8%, through reduced maintenance requirements, with additional benefit of increased wagon availability
- Contribution to the European Commission's goal of moving freight from the roads onto rails, which is an important step in developing a more sustainable transportation system, due to whole system cost savings which filter to freight operators and ultimately users.

SUSTRAIL CONTEXT



3. SUSTRAIL CONTEXT

The aim of WP1 was “*to provide information to support evaluation of the key system parameters which will ultimately influence and determine improvements towards freight sustainability and competitiveness*”, while WP2 was to “*define duty requirements for vehicles and track to potentially double the life of track components when combined with low impact vehicles*”.

This chapter contains a summary of the work done in Workpackage 1 “**Benchmarking**” and aspects of Workpackage 2 “**Duty Requirements**” to define the context into which the SUSTRAIL innovations would be introduced.

Section 3.1 briefly discusses the regulatory framework that any innovations in track or vehicles should comply with. The European rail freight industry, despite the efforts of the European Commission, is very inhomogeneous. So, to ensure results are relevant, SUSTRAIL examined three diverse freight systems operating on routes in Spain, Bulgaria, and the UK. This work is summarised in Section 3.2. The final section of this chapter summarises the future logistics requirements on the routes.

3.1 REGULATORY ENVIRONMENT

*More details in
deliverable D2.1*

Lead partner: UNEW

The European rail freight industry has developed from being fragmented: in 1990 each member state had its own regulations and standards; into having a common basis that allows trains to traverse borders without encountering logistic, operational, or legal barriers. The objective was to increase the competitiveness of the railways so they could recover market share that had been lost to road transport. The primary directives that aimed to achieve this were issued by the European Commission in 2001. The European Railway Agency (ERA) was established and is responsible for a number of Technical Standards for Interoperability (TSI) that give details of the harmonised requirements. Six of these are relevant to SUSTRAIL:

- vehicle TSI relating to the two subsystems
 - » rolling stock: noise
 - » rolling stock: freight wagons
- fixed installation TSI on infrastructure
- common TSI on safety in railway tunnels
- functional TSI
 - » operation and traffic management
 - » telematics applications for freight subsystem

Each TSI mandates the application of certain European standards.

There are also different national standards that have yet to be harmonised. These are imposed by the nations' standards organisation or other regulatory body and may be superseded by European standards. For example, in the UK there are still applicable Railway Group Standards, Network Rail Company Standards, and British Standards.

A parallel regulatory framework exists in the International Union of Railways (UIC) which is a member organisation that includes in its objectives to “promote interoperability, create new world standards for railways”. UIC publishes a set of leaflets that aim to achieve this and include standard construction measures and operating procedures. These leaflets are often used as the basis for European Standards; for example, the leaflet defining design calculations to be used for axles was withdrawn when its content was included in the European standards EN13103 and EN13104. Of particular relevance to SUSTRAIL are the standard drawings that UIC publishes for Y25 bogies.

More details in
deliverables: D1.2,
D1.4

Lead partners and
contributors: NR,
UNEW, ADIF, AFER,
NRIC

3.2 SUSTRAIL ROUTES

SUSTRAIL Workpackage 1 aimed to provide a benchmark of the current freight ‘system’ to establish the existing ‘zero state’ for subsequent comparative and enhancement activities. The benchmarking was designed to provide information to support evaluation of the key system parameters that will ultimately influence and determine improvements towards freight sustainability and competitiveness.

Data collection focussed on three selected European railway routes, identified by number on Figure 3.1:

1. the Mediterranean Corridor in Spain
2. the Bulgarian route from the Serbian border to Turkey
3. two key intermodal freight routes in the UK, from the ports of Southampton and Felixstowe to the North West of England.

These are all mixed traffic routes providing a wide diversity upon which to assess the freight system throughout Europe encompassing a wide range of freight, asset conditions, climatic influences and social/economic/cultural differences.

Also, tests and measurements were carried out at the test track at AFER’s Railway Testing Centre Faurei (route 4, not to scale, on Figure 3.1), which is the site of the demonstrations in Work Package 6.

Workpackage 4 made use of data from the Malmbanan heavy iron ore line in the north of Sweden (route 5 on Figure 3.1) and the Wooden Gates site on the UK’s East Coast line (route 6, not to scale).

Figure 3.1
SUSTRAIL routes



Capacity modelling was conducted to provide benchmarking of the current freight ‘system’, to establish the existing ‘zero state’ for subsequent comparative and enhancement activities. The benchmarking is designed to provide information to support evaluation of the key system parameters that will ultimately influence and determine improvements towards freight sustainability and competitiveness.

3.2.1 SPANISH ROUTE: MEDITERRANEAN CORRIDOR

The route from Castellbisbal to Silla is located on the Mediterranean coast of Spain and is about 350 km long. The route is electrified; the majority is double track, apart from a 57 km single track section. It has a signalling system of cab radio and colour light signals; train control is managed by automatic blocks.

All of the freight on this line runs from rail yard to rail yard without intermediate service activity at a typical line speed of only 75 km/h (compared to 100 km/h for passenger vehicles). When surveyed for SUSTRAIL the line was only carrying 86 freight trains per week (5 of these at the weekend) and the trains were relatively short. Bulk commodities such as iron and steel are transported along the line, as well as many cars, car parts and intermodal traffic.

Capacity modelling has indicated that due to a low volume of freight along this route, bottlenecks do not currently exist. Two sections of the route may become susceptible to bottlenecks in the future. Double-tracking the route throughout would prevent this.

3.2.2 BULGARIAN ROUTE: SERBIA TO TURKEY

The Bulgarian route runs from west to east between the Serbian and Turkish borders, approximately 360 km. The line is electrified west of Plovdiv (toward the capital, Sofia) and has a combination of single and double track. There are large variations in track condition; many sections of the track are in poor condition, with short sections in good condition. The signalling on this route is controlled by colour light and cab radio, while train control is managed by automatic blocks.

Freight traffic has a typical line speed of 75 km/h, apart from a 25 km section where it can travel at up to 120 km/h; the speed for passenger traffic on this line ranges from 65-130 km/h (indicative of the wide variation in track condition). The freight on this line is a combination of local and international traffic carrying a wide range of mainly raw materials (agricultural, chemical, minerals, and metals). It has an operational pattern of both non-stop and multi-stopping services and intermediate services are carried out along the line. There are between 10 and 30 trains using the line at any one time, but the average train-length is relatively short.

As part of the European TEN-T project, intermodal terminals are planned for construction initially at Sofia, and the second city, Plovdiv (the centre of rapidly increasing commercial and agricultural trade and activity); another two are then planned. There are two marshalling yards on this line (one at Plovdiv) and an intermediate station where only freight operations are carried out.

Capacity modelling indicates bottlenecks at the marshalling yards due to the length of processing times; this may be addressed through further research into yard operations. Bottlenecks visible near borders may be addressed by improving crossing procedures; currently these lead to a significant cost for the freight operator and raise questions over the sustainability of the entire route.

3.2.3 UK ROUTES: SOUTHAMPTON & FELIXSTOWE TO NORTH WEST ENGLAND

The UK routes studied in SUSTRAIL run between two important ports (Felixstowe in the Southeast and Southampton in the South) and a northern freight terminal near Manchester) using part of the West Coast Mainline (WCML), a combined distance of about 600 km. This is a major quadruple track electrified high-speed passenger route. The remainder of the routes are mainly double track with two short single track sections of which one, a 7 km stretch, is due to be doubled.

On the WCML (and other lines shared with passenger services), freight runs at up to 120 km/h, but on other sections freight runs at well below its potential speed (often around 50 km/h) due to slow lines and because of being stopped for passenger services. The routes are heavily used with some sections near ports recording over 300 freight trains per week, maybe an average of approximately 120 for the full route (having 2 paths/hour each way when capacity permits). A forecast for 2020 is that up to 200 freight trains will operate on the relevant part of the WCML and the greatest increase in rail freight traffic in the foreseeable future will be intermodal container traffic. Due to the complexity of the network, capacity modelling wasn't undertaken.

There are 4 main markets for rail freight in the UK:

- bulk commodities including coal, metals, construction traffic, oil and petroleum
- international traffic
- domestic intermodal
- railway infrastructure related

The major problem for UK rail freight is that there are very few routes with sufficient clearance to allow larger standard sizes of container to be transported by rail; this is gradually being addressed by Network Rail. As routes approach capacity, the work necessary to run longer trains along them is considered. Extra capacity is also expected on the High Speed 2 line when this is built. The SUSTRAIL solution of faster freight services (increasing the average speed for freight from 80 km/h to 120 km/h) will lead to improved interactions between freight and passenger traffic, so increasing capacity.

3.2.4 TEST TRACK: FAUREI, ROMANIA

The AFER test track at Faurei (see Figure 3.2) offers good conditions for demonstration activities, allowing a wide range of standard tests, especially those required for modified or new vehicles. It has a total length of 20.2 km with a maximum speed of 200 km/h and is electrified.

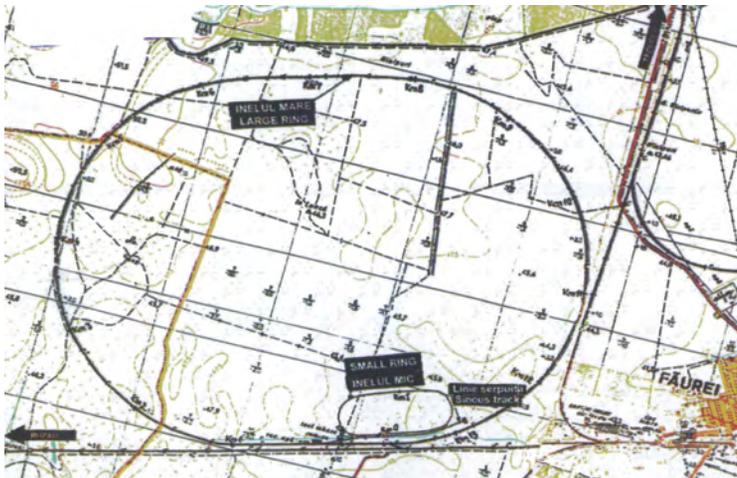


Figure 3.2
AFER's Railway
Testing Centre at
Faurei



The initial benchmarking for the SUSTRAIL project was carried out at the test track using a representative test vehicle (see Figure 3.3), the following tests were performed:

- track geometry (cant and gauge) and rail profile at selected locations
- wheel profile measurements of all wheels on the test vehicle
- static braking tests
- dynamic braking tests at 100 km/h and 120 km/h
- noise level measurements for the test vehicle passing at 100 km/h and 120 km/h.

Figure 3.3

Test vehicle - EAOS
Ordinary open high-
sided wagon



*More details in
deliverable D1.3*

Lead partner: UNEW

3.2.5 WAGONS

The two categories of wagons most commonly used on the selected routes and beyond, in partner countries, were flat wagons (as used for carrying containers) and open high-sided wagons (as shown in Figure 3.3). There are several variations of these that increase the commodities that they can transport.

The ages of wagons in operation, as reported to the SUSTRAIL project, covered a wide range (4 to 37 years). The highest proportion of older wagons (over 30 years) were observed to operate on the selected route in Spain.

The Y25 bogie and versions thereof (see Chapter 5) was reported to be the most common and widely used for freight wagons.

Most wagons were equipped with tread brakes / shoe brakes.

3.3 FUTURE LOGISTICS REQUIREMENTS

More details in deliverables: D1.5, D2.2

Along the routes, as in the whole of Europe, there had been a steep decline in rail freight carried after the year 2008. This was an impact of the economic downturn resulting from the financial crisis. In order to not draw the wrong conclusions from the development in rail freight along a route both general and route-specific developments need to be taken into account.

Lead partners: MARLO, NR

In general it is expected that freight traffic will increase significantly and the European efforts to increase interoperability and remove barriers to entry will encourage new operators to compete on the network.

3.3.1 SPAIN

Currently Spanish rail freight holds only 5% of the land freight market. The Mediterranean Corridor has the potential to increase capacity, as current freight volumes are significantly low.

This may be achieved through the development of rail freight into new markets alongside car parts and bulk commodities. A higher market share could also be captured through improved links with intermodal transport, a move to encourage modal shift from road to rail freight, and integration with the wider European Network. To accommodate increased freight volumes, it should be possible to increase train length and the number of wagons per train. Also, increasing freight speed to match that of passenger trains would reduce problems with their interaction.

If improvements can be made both locally (e.g. double-tracking the whole route) and to its integration with the European network, then a significant increase in utilisation might be expected.

3.3.2 BULGARIA

Rail freight in Bulgaria has approximately a 10 per cent share of total goods carried by surface transport. However, the EU has recognised the importance of the route as it has the ability to transport a wide variety of freight. With improvements to the line, including double tracking throughout the route, and the rolling stock the increases in capacity and potential are very significant.

There is potential for the average number of wagons per train to increase; however, further research is needed to clarify any restrictions regarding train length along this route. It is expected that increasing the average speed of freight along this route from 75 km/h to 120 km/h will lead to an increase in capacity. However, for such a scheme to be successful, significant investment in infrastructure along the route would be needed.

The main growth is expected to be of semi-finished and finished goods, textiles, and agricultural produce from Turkey heading toward Western Europe; it can be expected that the share of goods transported to and from the plants of the heavy industry, especially the metallurgical industry, will further diminish. There may be a slight increase in the share of coal and petroleum, as the economic development of the country of Bulgaria will go hand in hand with an increased use of energy.

3.3.3 UNITED KINGDOM

It is estimated that over 25% of freight containers originating from the Far East and shipped into ports like Southampton and Felixstowe are now transported onwards by rail. In the UK, rail freight will continue to grow by 26-28% by 2014/2015, compared with the year 2007. Important future market segments will remain the carriage of coal (for power production), ore (for the steel industry), and containers (for all kinds of cargo).

Consumer goods transported in containers have been the fastest growing goods category in rail freight over the past six years. Even the more moderate growth prediction of 4% would underline the containers' relevance for rail freight.

Another significant aspect is that there are plans to develop new port facilities at Bathside Bay on the other side of the estuary near Harwich, which would increase the number of trains from the combination of Felixstowe and Bathside Bay to 56 trains per day in 2030, which would increase the share of containerised rail freight.

The future planned expansion of the port of Felixstowe includes a third terminal capable of taking trains up to 30 wagons in length. In the port of Southampton, there is work underway to increase maximum train length to 775 m. Average train length is therefore expected to increase, and this will require investment in loops on the network and at terminals.

The demand for Class E ordinary high-sided wagons is still high and will always keep an important share on the market due to specific types of freight (bulk and aggregates), but the capacity available from the existing fleets is more than sufficient. An increase in the transportation of biomass is predicted to take 1/3 to 2/3 of the coal market over the next 15 years. New market segments are most likely the transportation of high value, low mass goods.

3.4 CHAPTER SUMMARY

This chapter has briefly described the context into which the SUSTRAIL innovations will be introduced. There are many regulatory, commercial, geographical, and logistical factors that need to be considered. These were addressed in the Business Case Workpackage, WP5, described in the next chapter.

SUSTRAIL BUSINESS CASE - A HOLISTIC APPROACH



4. SUSTRAIL BUSINESS CASE - A HOLISTIC APPROACH

The specific aims were to “*consider the economic business case and implementation issues associated with the vehicle and track options developed in WP3 and WP4 respectively. Amongst other aspects, the Workpackage will act as both an iterative filter for the options developed in WP3 and WP4 in order to help focus the engineering development to those options which are likely to have greatest overall net benefits, as well as providing a final business case appraisal for the preferred option.*”

4.1 INTRODUCTION

SUSTRAIL Workpackage 5 ‘Business Case’ was linked to the vehicle (WP3) and track (WP4) workpackages that are presented in Chapters 5 and 6 respectively.

4.2 INTRODUCTION TO THE BUSINESS CASE APPROACH AND ITS INTEGRATION WITHIN THE PROJECT

The SUSTRAIL project is more than technical innovations. At all stages within the project there has been involvement of disciplines such as economics, and human factor analysts, and substantial stakeholder engagement. This is important to ensure that the engineering research is directed at areas which best meet the overall objective of the project, namely to improve the competitiveness of rail freight. The Business Case workpackage contributes to the overall project objective by

- helping to prioritise innovations for final assessment
- aiding the project to identify means to integrate the engineering innovations into the industry, including phasing in of novel technologies
- developing strategies for the equitable redistribution of whole-system savings
- helping promote and facilitate industry, government, and other stakeholders’ ‘buy-in’

To this end, work to understand what is needed by the rail freight industry (in terms of technical innovations in the vehicle and track) to meet the overall policy objective of increasing the market share of rail freight, was embedded within the early stages of the SUSTRAIL project; in order to meet its objectives, the engineering research had to align and be optimised to this end.

Figure 4.1 presents the interaction of the Business Case development with the rest of the project. The first part of this chapter (sections 4.3 to 4.5) reports on the development of the Business Case up to the prioritisation of the engineering innovations. It also discusses what is meant by a ‘Social Cost Benefit Analysis’ and how this has been tailored to the context of SUSTRAIL, including the Life Cycle Cost (LCC), and Reliability, Availability, Maintainability, and Safety (RAMS) methodologies. Section 4.7 considers the role of access charges in the assessments as they are important to redistribute the savings from reduced track maintenance associated with vehicle improvements to the vehicle operator to incentive take up. Section 4.8 discusses the emerging results from the LCC/RAMS and wider Cost Benefit Analysis (CBA). Unfortunately due to print deadlines it is not possible to report the finalised results as these are still under revision. Section 4.9 considers the implementation case for the innovations.

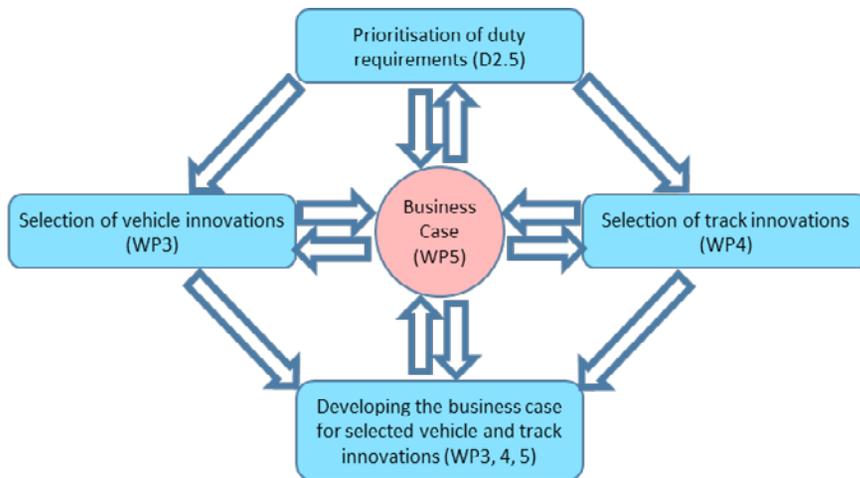


Figure 4.1
Integration of the
Business Case within
the project

4.3 DUTY REQUIREMENTS AND INNOVATION SELECTION

Lead partners:
UNILEEDS, USFD

An important step in the first year of SUSTRAIL was the definition of duty requirements. These included: essential duty requirements which must be met by the innovative freight wagon and track, for example, a large number of Technical Standards for Interoperability (TSIs) and standards applicable to railways which are expected to remain fixed; and also duty requirements for improvement, which specify changes above and beyond the essential duty requirements which will allow rail freight to become more sustainable and gain market share.

A large number of ideas for new duty requirements were considered. In order to prioritise among them they were assessed against a set of criteria derived from the Business Case framework:

- availability
- cost
- service quality
- environmental footprint
- technical viability: the operators', IM's, and research team's judgement about whether the duty requirements were:
 - » capable of being addressed by the project with 3 years' intensive research
 - » implementable by the industry

The prioritisation exercise made use of the information available at this stage of the project, including operators' and IMs' inputs, as well as the evidence from the SUSTRAIL research, and the findings of a workshop focusing on this topic.

Emerging from the prioritisation was the set of new duty requirements shown in Table 4.1. These were rated High/Medium/Low priority, with the implication that: High priority items would be pursued most urgently, using the majority of the resources; Medium and Low items would be given less priority, however even the Low items have potential – their Low priority reflects greater risks (in terms of technical viability) and/or smaller apparent rewards.

These duty requirements are about determining what the SUSTRAIL improvements should be, in terms of the parameters targeted, the direction of change, and, particularly where research evidence exists, the magnitude of the target.

Priority Level	Duty Requirements for Improvement	System
High	Modest increase in freight speed (e.g. 120 to 140 km/h UK; 100 to 120 km/h ES,BG)	whole
	Optimise axle load limits (22.5 t / 25 t / 17 to 20 t)	whole
	(20%) reduction in energy used by rail vehicles + Vehicle Green Label	vehicle
Medium	Improve bogie design to reduce lateral forces (by 50%)	vehicle
	Reduce vertical ride force to match passenger vehicle at equivalent axle load (by suspension improvements)	vehicle
	(20%) reduction in unsprung mass of freight vehicle	vehicle
	Uniform vertical stiffness (track) - optimise between 50 to 100 kN/mm	track
	Optimise (potentially double) service life of track components	track
	Combine components that have a similar service life (harmonise mean time between failures: MTBF)	track
	Reduced rate of tolerable defects	track
More reliable insulated rail joints (life*5)	track	
Low	Independent power supply (wagon or train based) - for braking & refrigeration	vehicle
	Increased loading space	vehicle

Table 4.1
Duty requirements for improvement, by priority level

The duty requirements were considered along with other factors to determine which innovations to take forward for analysis or to include in the physical demonstrator. More details are given in chapters 5 and 6 for the vehicle and track respectively.

4.4 THE METHODOLOGY FOR THE COST BENEFIT ANALYSIS

Central to the SUSTRAIL Business Case is the impact on stakeholders in the industry, including the infrastructure managers (IMs), freight and passenger operators, and the end users whose freight is being moved. It needs to be demonstrated that for these stakeholders the benefits of the SUSTRAIL innovations outweigh the costs (see Table 4.2).

Table 4.2
Business case impact
table: top level

Groups				
	IMs	Train Operators	End Users	3 rd Parties
Impacts	changes in costs and revenues	Freight Operators: changes in costs and revenues Passenger Operators: changes in costs	changes in costs and benefits	Environmental Externalities: CO ₂ & noise Government: grant or subsidy requirements

Therefore the Business Case includes a cost-benefit analysis comprising:

- financial analysis of the impact on IMs, train operators, end users, and government, in terms of net present value (NPV) and internal rate of return (IRR): further details follow
- a socio-economic cost-benefit analysis covering all parties, in terms of NPV, IRR, and benefit:cost ratio (BCR)

More widely, the SUSTRAIL research is expected to contribute *to a more sustainable European freight sector*. According to its description of Work, this increase in sustainability is to be achieved through:

1. attracting freight market share towards rail from less sustainable modes (road in particular) by “designing the freight vehicle-track system for higher delivered tonnage with improved availability at reduced cost”
2. increasing the sustainability of rail freight itself, both in economic and environmental terms, for example by reducing CO₂ emissions or noise per tonne-km

SUSTRAIL will assess how the proposed changes in the vehicle-track system will impact initially on costs and on system performance, and finally on these wider goals of rail market share and sustainability, illustrated in Figure 4.2. These wider impacts will be integrated into the cost-benefit analysis as far as is technically feasible.

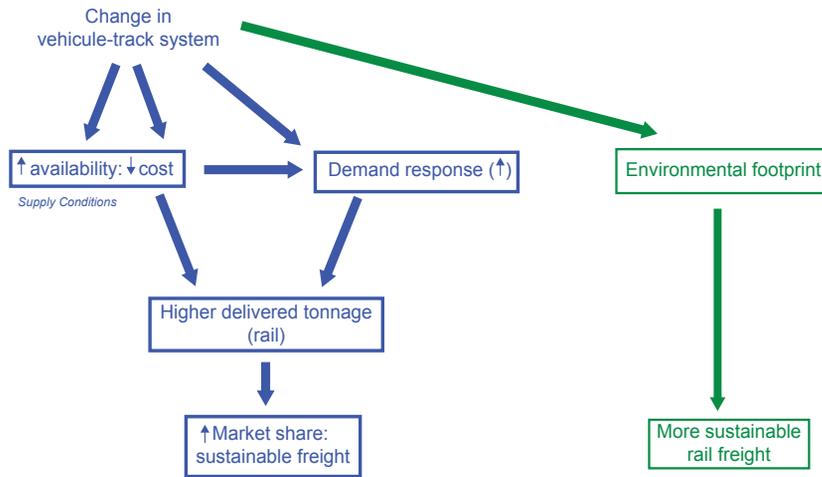


Figure 4.2
Impact pathways
from the SUSTRAIL
innovations to
sustainability goals

The changes in costs were estimated using Life Cycle Costing (LCC) analysis for both the IMs and train operators, and the impacts on whole-system performance were measured using Reliability, Availability, Maintainability, and Safety (RAMS) analysis (see below).

Implications for user and environmental benefits were estimated in three case studies, based on the SUSTRAIL routes in UK, Spain, and Bulgaria. An overview of the methodology for assessing these benefits is given below. This work includes demand analysis for the purpose of estimating:

- value of the change in the vehicle-track system to end-users
- end-users' expected demand response to the rail freight system improvement
- implications for market shares

These user and environmental benefits are reliant on the outputs from LCC and RAMS analysis, and also on assumptions about track access charges between IMs and train operators. Task 5.3 of SUSTRAIL was dedicated to understanding the potential for differentiated access charges reflecting the relative damage cost of different vehicle-types. In the Business Case, track access charges influence the flow of revenue from train operators to the IM, and hence the distribution of whole-system savings.

Moreover, as noted in Section 4.2, the Business Case is also concerned with implementation of the vehicle and track innovations proposed by the project. IMs and train operators have a wide range of technologies in use at any time, and the innovations need to be compatible with these to ensure that the operation of the railway system remains integrated. Finally, work on technical implementation focused on interfacing the innovations with existing track forms and vehicles, human factors, and operational aspects.

In summary, therefore, the outputs of the Business Case for the selected SUSTRAIL innovations will comprise the following items (Table 4.3).

Table 4.3
Business Case outputs

Item	Analysis outputs
1.	Description of the innovation
2.	Rationale for the innovation
3.	LCC and RAMS analysis: main findings
4.	Cost-benefit analysis (CBA): » financial case for industry stakeholders (NPV, IRR) » socio-economic case (NPV, BCR, IRR) » impacts on rail market share
5.	Environmental impact (CO ₂ and other emissions)
6.	Technical implementation and phasing: recommendations

Given that both track and vehicle innovations were developed in the engineering analysis, it was decided to undertake the LCC/RAMS and CBA for a number of scenarios to reflect the Duty Requirements of the project, but to allow some degree of optimisation of the recommended improvement. These were:

- Base case: Current vehicle and current track at current freight speed (UK route 120 km/h)
- SUSTRAIL 0: Improved vehicle and current track at current freight speed
- SUSTRAIL 1: Improved vehicle and improved track at current freight speed
- SUSTRAIL 2: Improved vehicle and improved track at higher freight speed (UK route 140 km/h)

4.5 LIFE CYCLE COSTING (LCC) AND RAMS

More details in deliverable D5.1

Lead partner: LTU

LCC and RAMS analysis is a challenge because the railway transport system is complex from both a technical and organisation perspective and comprises several different parties, each one with its own objectives and strategy in maintaining its assets. The development of the railway system has also been carried out on a national basis leading to system hindrances such as differences in standards and different technical solutions, e.g. different track gauges. An obstacle to getting data for benchmarking or LCC-calculations is that deregulation and outsourcing has resulted in data that had previously been available becoming confidential and sensitive in the prevailing competitive environment. There can be many different reasons why there is a problem in getting access to data. E.g.

- failure frequencies of vehicle components could be unknown if overhauls were undertaken at different depots
- wheels are constantly being shifted between wheel-pools of different wagons and owners
- data could be located within different parts of an organisation in different formats
- data does not exist due to the absence of a measurement strategy
- supplying data does not align with a stakeholder's business goals
- difficulties in estimating e.g. costs and maintenance actions for new solutions which are only in the design stage

Hence the RAMS and LCC simulation had to be performed on a subset of the total number of innovations presented in WP3 and WP4. The innovations/solutions that were excluded from the simulation are discussed from a more qualitative point of view.

The RAMS and LCC models were developed to assess the innovations from a holistic approach that aimed to reflect how the track and the wagon systems interact. In the model, maintenance actions on the track were affected by the more track-friendly SUSTRAIL wagon having been introduced. The economic benefits for the Infrastructural Manager (IM) can be quantified by considering the results of vehicle simulations. Effects in the opposite direction, how the track will affect the wagon, have not been implemented in the model due to lack of data.

4.5.1 RELIABILITY, AVAILABILITY, MAINTAINABILITY, AND SAFETY (RAMS)

RAMS of a system is the qualitative and quantitative indicator of the degree that the system can be relied upon to function as specified and is both available and safe. It provides a means by which the performance of an engineering system can be assessed, analysed, and improved. The concept of RAMS analysis has been evolving over decades, particularly in the field of product assurance, and is described as dependability management in some fields.

A dependable railway system can only be assured through adequate understanding of the interactions of RAMS elements within it. In addition, the specification and achievement of the optimum RAMS combination for the system should be well managed. The specification of RAMS requirements is a complex process; a systematic process for doing it and demonstrating that they are achieved is defined in the standard EN 50126. The definition and interaction of RAMS elements is given in this standard, but a process based on the system lifecycle and tasks within it for managing RAMS is presented here. The procedure for the creation of a RAMS programme, based on specified requirements is demonstrated to serve as guidance for a practical implementation. There are several tools, techniques, and approaches that can be used for RAMS analysis. However, the selection of an appropriate tool depends on the system under consideration and on some other factors. For SUSTRAIL we have used a simulation implementing a combination of some of the techniques mentioned in EN 50126. Figure 4.3 shows a typical flow chart used for the specification of RAMS requirements as well as the investigation of the achievement of the target for each element.

In this study, the states of the wagon and track system are monitored using stochastic simulation of failure events. The model is developed using an event-driven simulation tool called SIMLOX that enables detailed analyses of the variation of technical system RAMS performance over time given different operational and logistics support situations. During the simulation, operations generate failure events, which in turn create a need for maintenance personnel, actions, and other resources.

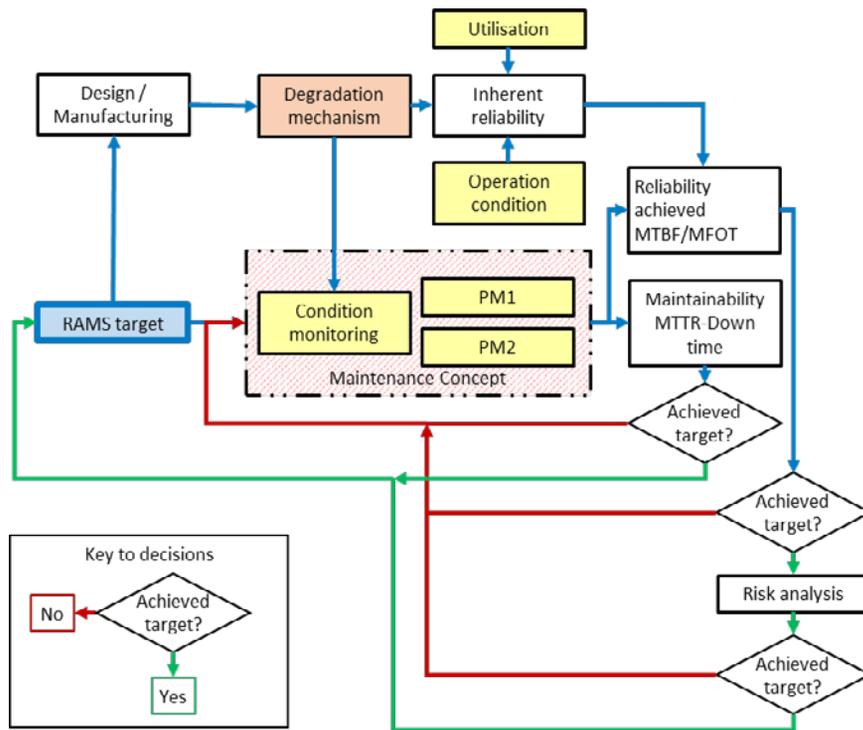


Figure 4.3
Specification of
RAMS target
considering the
interaction of its
elements

The flowchart of the RAMS simulation is shown in Figure 4.4. The first stage is the simplification and characterization of the track section and wagon. This involves a description of the technical system breakdown structure and extraction of design features relevant to the RAMS study.

The second stage is the model building, where models are developed to describe the stochastic failure process and logistic support plan for the system. The maintenance strategy and logistics support plan for wagon and track system include preventive (PM) and corrective maintenance (CM or repair). The PM and inspection schedules were based on standard practices and expert information for both wagon and track systems. The preventive replacement of wagon components was based on the recommended interval/lifespan and are carried out when the wagon is in the workshop for inspection or CM. The failure characteristics of the benchmark wagon and track systems were obtained from relevant historical records of maintenance service providers, while the failure characteristics of the proposed SUSTRAIL design were based on expert judgment. In the model, failure events are generated using a stochastic process based on the estimated failure rate for each failure mode.

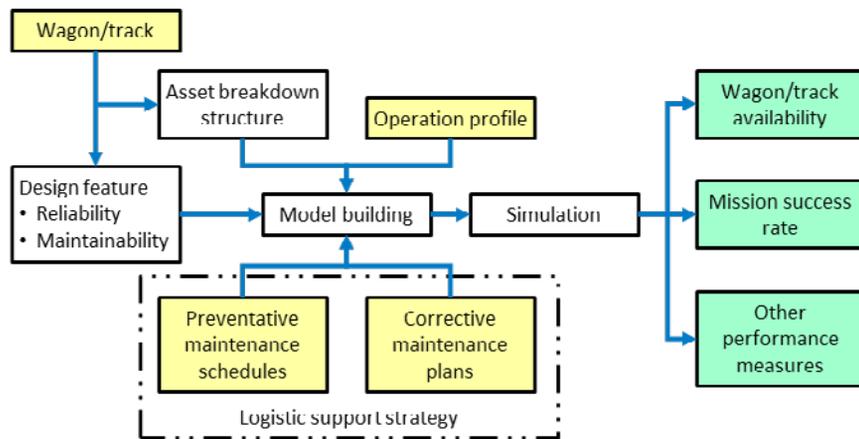
The third major input into the model is anticipated train mission profile or traffic schedule on the line. The operation profile of the wagon and traffic on the route were specified in the format required by the simulated tool (not comprehensively as would have been necessary for a typical traffic

simulation and management tool). In the wagon simulation, a wagon was considered to make a daily return trip of about 1,500 km taking about 16 h. For the track RAMS simulation, it was assumed that there were between 23 and 29 trains per day, about 200 per week for the selected route.

The outcomes of the model are RAMS measures including: number of failures of each track section; expected downtime in hours; expected states of the track sections; and the mission success based on the planned mission profiles. For instance, in the model, a wagon mission is not accomplished if:

- the wagon is withdrawn from a train when it fails during operation
- a wagon is not available to start a scheduled mission (trip)

Figure 4.4
Description for RAMS
simulation approach



4.5.2 RAILWAY LCC

Life-cycle costing can be described as the economic analysis process carried out to assess the total cost of acquisition, ownership (operation and maintenance), and disposal of a simple or complex system. It is either applied to the entire life-cycle of a product, or one life-cycle phase, or combinations of different phases. The basic aim of a LCC analysis is to provide support for decision making in any or all phases of a system's life-cycle. An important objective in the development of LCC models is to identify costs drivers, i.e. those cost elements that have a major impact on the LCC. In relation to the SUSTRAIL project, the LCC analysis was carried out to support decisions for some of the innovations suggested by the project towards a sustainable railway vehicle and track.

An important aspect in LCC analysis, besides the cost of acquisition and termination, is the estimation of the RAMS related costs. As discussed in Section 4.5.1, this is stochastic in nature and depends on many parameters. Figure 4.5 highlights some parameters obtained from a RAMS simulation and later translated into operation and maintenance costs.

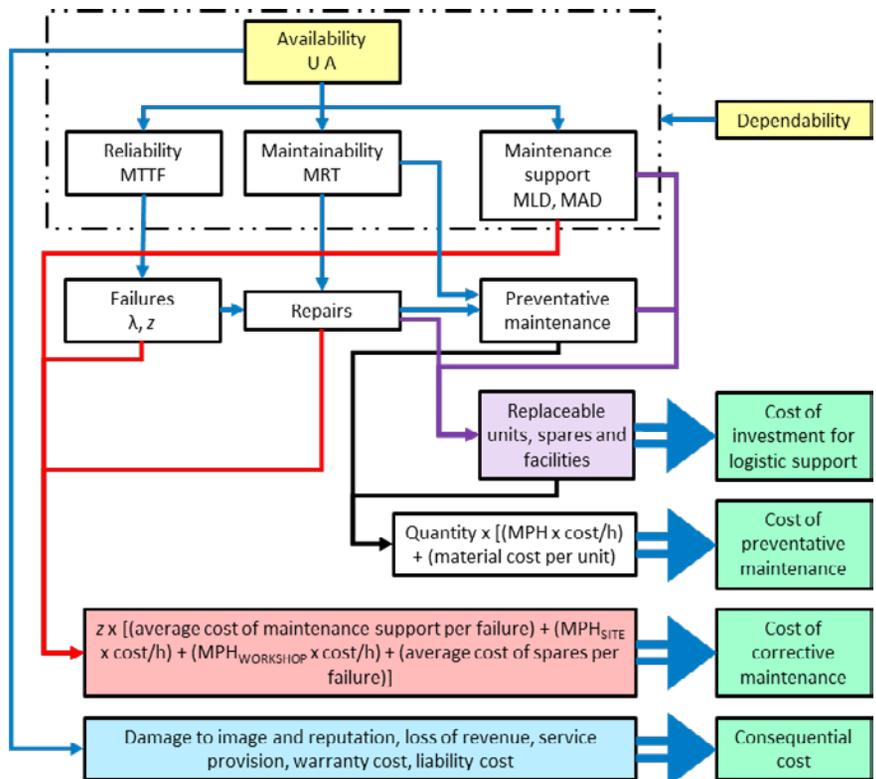


Figure 4.5
Connection between RAMS and LCC model for the operation and maintenance phase of the systems

The LCC approach follows the outcome of the RAMS simulation; it is illustrated in Figure 4.6.

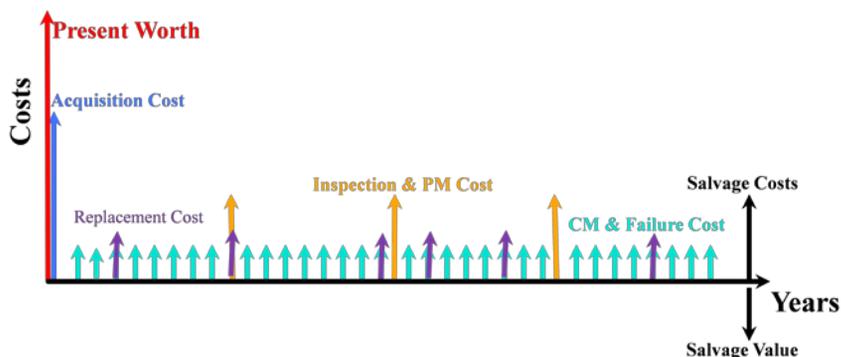


Figure 4.6
Demonstration of cost flow over life span

For the wagon and track LCC model, all the cost elements were categorised into four aggregate groups:

- Life acquisition cost (investment and renewal for track)
- Life operation cost
- Life support cost (maintenance cost for track)
- Life termination cost

The grouping of the cost elements into the four aggregates is shown in Figure 4.7 and Figure 4.8. In the LCC modelling for track, only significant and distinguishing costs were taken into consideration for the alternatives investigated. I.e. costs (especially those within the life support cost aggregate) that are considered to remain unchanged in the alternative scenarios are not shown in the total LCC.

Figure 4.7
Cost tree and break down structure for wagon

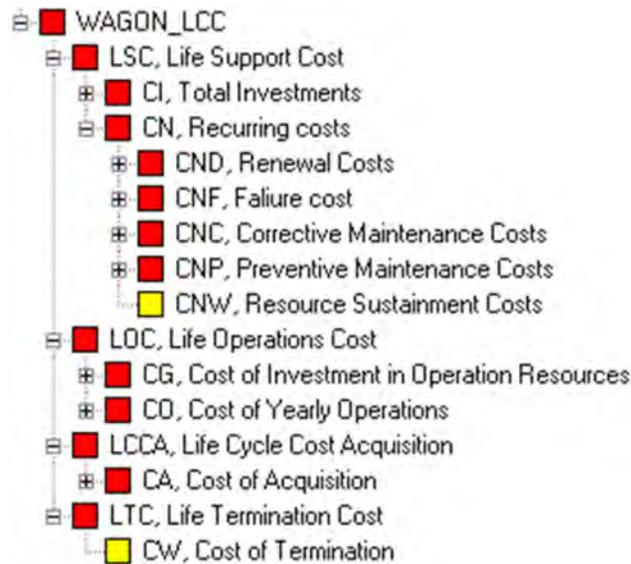
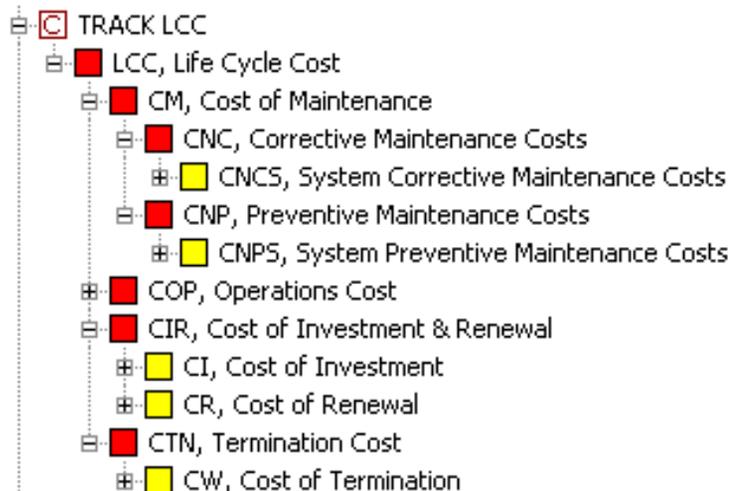


Figure 4.8
Cost tree and break down structure for track system



4.6 TRACK ACCESS CHARGES

More details in deliverable D5.3

A key economic interface between infrastructure managers and freight operators is the track access charge regime: payments by train operators to infrastructure managers for the incremental costs associated with running the train service. Access charges are the key mechanism by which infrastructure cost improvements are passed through to freight operators and, in turn, to freight users. Similarly, suitable discounts in track access charges for different vehicle types can incentivise the adoption of track friendly vehicles. This is an important incentive given that track friendly vehicles may imply higher capital costs for operators. To build a financial case for operators to adopt these vehicles, reductions in on-going costs need to be present and access charges are such a cost (they are incurred whenever the vehicle is used).

*Lead partner:
UNILEEDS*

In SUSTRAIL new empirical research has been undertaken to understand how costs (and not just damage) vary with traffic of different types. The research within SUSTRAIL on access charges has advanced the understanding of railway infrastructure marginal costs associated with railway traffic and also researched how implementing price incentives (via differentiated access charges) has influenced operator behaviour. New work has been undertaken in integrating the two main approaches (engineering and econometric) to analysing the direct cost to the infrastructure manager associated with running additional traffic. Further new work has been undertaken to understand renewals costs and traffic disaggregation in the econometric approach.

Work has also been undertaken to assess the effectiveness of existing access charge differentiation e.g. by vehicle characteristics. The country with the most highly differentiated track access charges by type of vehicle is Britain, and it appears that even the relatively modest differentiation now in place is sufficient to influence purchasers of new vehicles to fit track-friendly bogies. The current charge differentials are not in general high enough to lead to premature retirement of existing vehicles. However, were the 'central' charge to be raised (as was discussed during the most recent review of track access charges during 2013) then the differential either side of the central charge would be greater, probably providing a greater incentive to retire the least track-friendly wagons early and/or to invest in the 'most' track-friendly bogies. Of course, this would be likely to have knock-on consequences for operator costs and the overall competitive position between rail and road freight.

Differentiated access charges may be ineffective due to:

- the long lives of wagons; this has led to the current low level of replacement investment
- the relatively small size of discounts for track-friendly bogies

- vehicles running in a variety of countries (common in continental Europe), either on international traffic or because they may be moved between countries in the course of their lives; incentives for track-friendly bogies (however small) are not applied in every country
- the risk involved in buying a more expensive wagon that will only recoup its cost if differentiated access charges continue throughout its life

The effect of these factors might be lessened by introducing larger differentials, but if these exceeded differences in direct cost then this would be in contradiction to existing EU legislation.

The introduction of noise-differentiated charges, in so far as reduced noise emissions may be linked with track-friendly bogies, may serve to increase take-up of track-friendly bogies across mainland Europe. However, the diversity of charging structures and levels found in Europe means that the impact of incentives is limited.

There is less evidence that track access charges could be used to encourage speeding up of freight trains to increase track capacity, particularly since faster vehicles are more damaging. Clearly there are fears that this could lead to complex charges, with different incentives leading in different directions. It appears that the use of charging to encourage the operation of freight trains at higher speeds needs to be simple and its implications need careful thinking through.

4.6.1 STRATEGY FOR ACCESS CHARGE DIFFERENTIATION IN THE SUSTRAIL BUSINESS CASE

To be useful to the wider context of SUSTRAIL, the research contributions have to be interpreted within the EC charging principles such as Directive 2001/14. These EC directives imply that while charges should be based on direct (marginal) cost, mark-ups are allowed provided that they are non-distorting. We proceed with the current access charge systems, both in terms of levels of charges and existing differentiation in each of the three case study countries as the ‘base case’.

In terms of enhancing the rail freight offering and incentivising the implementation of the SUSTRAIL innovations, the project requires access charges to:

1. Pass through infrastructure cost savings resulting from technological innovations to the infrastructure (as studied in WP4) to freight and passenger operators via lower track access charges and ultimately to freight and passenger users. Not all infrastructure cost savings are passed through, only the proportion which is variable with traffic as this reflects the change to marginal costs of running traffic.

2.Redistribute infrastructure cost savings to freight operators if freight operators utilise track friendly vehicles.

The principle that access charges should reflect the infrastructure damage (and thus cost) incurred from running a train service, implies that the whole cost saving of any infrastructure cost reduction should be fully reflected in changes in access charges. So, if infrastructure costs decrease 5% across all vehicle types as a result of the SUSTRAIL infrastructure innovations, then access charges should fall 5% for all services. This effectively means that the whole of the saving relating to the proportion of cost variable with traffic is passed through to the operators of train services (both passenger and freight). This reflects the fact that the cost to the infrastructure manager to remedy damage from a train service has fallen. Such a mechanism allows the proportion of infrastructure cost recovered from charges to remain the same before and after the innovations.

Implication: With respect to Infrastructure innovations, the proportionate change in infrastructure cost will be reflected in the same proportionate change in (variable) access charges relative to the base case.

With respect to infrastructure cost savings arising from innovations to the vehicle, the principle that access charges should reflect the damage (and thus cost) caused to the infrastructure from running the service implies that 100% of the infrastructure cost reduction should be passed through to operators as a reduction in access charges. However, this reduction should be specific to those vehicles that do the lower amount of damage (as opposed to being applied to all vehicles).

Implication: With respect to Vehicle innovations the absolute change in infrastructure costs resulting from running the less damaging vehicles should be passed to the operators of those vehicles.

The above two strategies to adjust track access charges ensures that, with respect to infrastructure improvements, the cost recovery rate for the infrastructure manager remains the same and with respect to vehicle improvements, that operators pay to reflect the damage that they cause to the infrastructure.

Following the LCC analysis and bespoke engineering damage simulation of the vehicle on the track undertaken in SUSTRAIL WP3, the access charge reductions (relative to the base vehicle(s)) were those shown in Table 4.4.

	SUSTRAIL 0 – vehicle improvement	SUSTRAIL 1 – vehicle and track improvement	SUSTRAIL 2 – vehicle track and speed improvement
Vehicles within the SUSTRAIL vehicle class	10.4%	17.4%	15.2%
Other vehicles	0%	6.9%	4.8%

Table 4.4
Access charge reduction from base in each of the scenarios

Note that the SUSTRAIL vehicle requires a discount because it does less damage to the track than the base vehicle.

More details in
deliverables: D5.1,
D5.2, D5.6

Lead partners: LTU,
UNILEEDS

4.7 EMERGING RESULTS OF THE LCC/RAMS AND CBA

The LCC and RAMS technical analysis (D5.1) is first summarised. The payback period for the vehicle is then discussed under a number of scenarios depending on the final outturn (mass production) capital cost, the redistribution of infrastructure cost savings to operators via access charges, and the discount rate assumed. Then we discuss the social cost benefit analysis. At the time of writing, the Cost Benefit Analysis for each of the case study routes in the UK, Spain and Bulgaria was still to be finalised. As such we only provide a qualitative assessment.

4.7.1 SUMMARY OF LCC/RAMS ANALYSIS

The LCC and RAMS analysis was able to model the majority of the innovations in the conventional SUTRAIL vehicle. In addition, due to limitations in cost data availability, only one track innovation (Premium Rail Steel applied to curves of less than 1200 metres) could be considered. This reflects the difficulty in undertaking LCC and RAMS for innovations within the research phase of a research and development project.

The result of the RAMS simulation for the SUSTRAIL vehicle was that the technical performance of the SUSTRAIL wagon was better than that of the benchmark wagon. The estimated availability of the benchmark wagon was about 95% while that of the SUSTRAIL wagon was estimated to be 99%. The main factor responsible for the lower availability of the benchmark wagon was the logistic and waiting time at the workshop. In addition, the mission success rate of both the SUSTRAIL and benchmark wagons was similar. From the cost perspective (see Figure 4.9), although the initial cost of acquisition of the improved wagon was approximately 75% higher, the reduced cost of maintenance and failure pays off in the long run (see section 4.7.2 for a further discussion of the payback period for the vehicle).

Furthermore, the availability of the benchmark track and wagon, benchmark track and improved wagon, improved track and wagon, and improved track and wagon with speed increase are estimated to be 95%, 97%, 99% and 97% respectively. Even though these are similar, the reduced cost justifies the implementation of the SUSTRAIL scenario (improved wagon and track) without speed change. More simulation is needed to validate the performance of the proposed improvement with speed change.

It is estimated that for the curves on the simulated UK route the improved wagon alone will give at least a 5% reduction in the life cycle cost over 30 years. If the track uses premium rail steel together with the improved wagon there would be approximately a 61% reduction in the LCC. In the 'track improvement with speed change' scenario, the expert assessment

was that the reduction in LCC would be approximately 43%. It is important to note that this LCC analysis has been "partial" in nature; the infrastructure improvements only apply to curved sections of track with radii less than 1200 metres and so only curves of this radii were included in the LCC cost base. Thus the actual saving from premium rail steels will be smaller as a percentage of total route cost than that indicated in the LCC analysis. This adjustment is case study route specific.

In the cost benefit analysis work (Deliverables 5.2 and 5.6) the costs were aggregated to the case study route levels. This stage applies the LCC to the entire route cost structure rather than the partial structure. As an indication of magnitude, for the UK route, the LCC saving from the track improvement is of the order of 9% although this route has a relatively high curved track length.

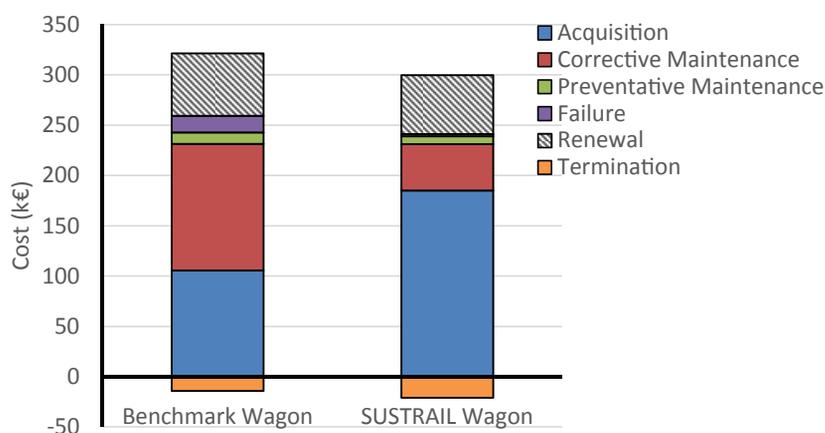


Figure 4.9
Wagon LCC (3% discount rate and not including access charge reduction)

4.7.2 WAGON PAYBACK SCENARIOS

The payback period refers to the number of years after acquisition of the SUSTRAIL vehicle that the operator makes a net present value benefit over the conventional vehicle. It is important because although the LCC analysis indicates a net benefit to the operator from using the SUSTRAIL vehicle, in practice operators will be unwilling to take on the risk in the forecast unless the payback period is sufficiently short.

The LCC analysis reported above considered the majority of factors affecting the operation and acquisition of the SUSTRAIL vehicle. However it did not consider any discount in track access charges associated with this vehicle relative to the base (benchmark) vehicle. Such a reduction can be justified because the use of the SUSTRAIL vehicle results in less damage to the track and less remedial cost to the infrastructure manager. Section 4.6 set out the access charge reductions for each scenario.

In addition, the biggest hurdle for achieving a competitive payback period is the cost of acquisition (capital cost). The LCC analysis indicates that the SUSTRAIL vehicle's capital cost is 175% of that of the benchmark vehicle. There is much uncertainty in this figure. In particular it is not unreasonable that under mass production scenarios the capital cost increase could fall to only one half of the current increase over the benchmark vehicle (137.5% of the benchmark vehicle's capital price).

Finally, in terms of specifying payback scenarios, it is important to recognise that commercial organisations require a return on capital; analysis indicates that the rail freight market requires 7% real return (9% nominal). We tested this against the 3% assumed in the LCC analysis (3% is close to the social discount rate used in the cost benefit analysis).

Table 4.5 shows the payback period for four scenarios. To yield a payback of less than 10 years it would appear that it is essential that the capital cost is reduced. However, this should be achievable so should not be a barrier to the adoption of the SUSTRAIL vehicle in the industry.

Table 4.5
Payback period for
the SUSTRAIL
vehicle under various
scenarios

Access charge discount	Discount rate	Capital Cost (relative to benchmark vehicle)	Payback period (years)
No	3%	175%	23
Yes	3%	175%	18
Yes	3%	137.5%	5
Yes	7%	137.5%	7

4.7.3 QUALITATIVE ASSESSMENT OF THE SOCIAL COST BENEFIT ANALYSIS

Overall the social cost benefit analysis shows a positive benefit to all groups considered under each of the three SUSTRAIL scenarios: that is the infrastructure managers, the freight operators, freight users, 3rd party beneficiaries of environmental improvements, and government. Further, because there are overall cost savings, the traditional benefit to cost ratio for the improvements is negative, indicating that these innovations have a positive impact on society on a cost case, even before any user and environmental benefits are factored in. This is a strong result. The emerging modelling indicates that it could lead to a 10% increase in the rail freight market for container traffic in the UK (SUSTRAIL 1 scenario).

Table 4.6 summarises the key impact groups and how the SUSTRAIL innovations impact them. The trends are clear, but the magnitude of the benefits will depend on the exact scenario considered. However, the conclusion from the cost benefit analysis is that there is a strong social case for the innovations. Therefore the potential barrier for the SUSTRAIL innovations is whether the vehicle innovation has a sufficiently short payback time for commercial organisations to adopt it (see discussion above) rather than whether there is a net social benefit.

User group	Description	Net benefit
Infrastructure manager	Reduced LCC from either: » Track innovation » Less track damage from track-friendly vehicle	
Operator	1) Reduced LCC for vehicle 2) Reduced track access charges for vehicle from either: » Track innovation » Less track damage from track-friendly vehicle	
Freight users	Better freight service resulting from: » Improved price ((eventual) pass through of operator cost savings due to competitive market forces in freight market) » Improved reliability » Improved speed of service (SUSTRAIL 2 only)	
Environment	Reduction in CO ₂ resulting from the modal shift of freight from road to rail Reduction in noise	
Government	Reduced subsidy to the railway due to reduction in LCC of the infrastructure manager	

Table 4.6
Summary of the
Social Cost Benefit
Analysis

*More details in
deliverables D5.4 and
D5.7*

*Lead partners: NR,
GCLAS*

4.8 PATH TO IMPLEMENTATION

Innovations cannot be considered to be useful if they are not implemented. The wide range of innovations considered within the SUSTRAIL project all have potential benefits, but this alone will not necessarily mean they will be taken up by the rail industry. It is important within the project to consider the barriers to their implementation and demonstrate reasons to adopt them.

4.8.1 TECHNICAL IMPLEMENTATION

Railways have been established across Europe for over 100 years, during this time continuous improvement has resulted in an evolving system that requires careful consideration for the introduction of new technology and processes to ensure they are compatible with the existing environment. This aspect is considered for all the SUSTRAIL innovations as their introduction will be progressive and will therefore run alongside the existing systems that they will ultimately replace. A good example of this is the service life of wagons; since this is approximately 35 years or longer, conventional wagons and SUSTRAIL wagons will operate alongside each other for many years.

This section considers the feasibility of the innovations being developed into a useable product and the steps required to do so, such as product approval and testing etc. It will also consider phasing issues and dependencies.

It is important to identify the key beneficiary of a given innovation as knowing the issues they face will enable us to fully consider the implementation barriers. A good example of this would be improved vehicle suspension, which makes the vehicle initially more expensive to buy, but this is offset by reduced track damage which could in turn lead to reduced track access charges for the vehicle operator. Purchase price, maintenance, and operating costs are all of course key decision points for any product, but reliability is key to avoid unexpected issues. Legislation and standards can also play a key role in driving the adoption of new technology.

Each innovation has been considered by the appropriate project partner for the following criteria:

- Innovation opportunity / need
- Next development steps / deployment
- Issues and dependencies

Table 4.7 summarises the technical implementation issues surrounding the vehicle innovations. Disc brakes are the only Work Package 3 innovation that is available in 2015 as they have a manufacturer or supplier already in place for various passenger train and locomotive applications; the others are not commercially available so dates have been predicted. These are based upon the time to complete the next development phases and include time for certification / approvals. However, they should be considered as the earliest possible dates for implementation. The SUSTRAIL innovation owners will pursue future development opportunities.

To help identify the potential size of the market for the SUSTRAIL wagon, information was gathered on the number of intermodal wagons that are on the UK network. Research suggests there are more than 4000 British Railways era wagons plus in excess of 4000 newer ones, giving a minimum total of approximately 8000 units in total. Information published by Freightliner (UK Freight Company) states that the current average life span for a wagon is 35 years; this would suggest a replacement rate of around 214 wagons per year for the UK alone at the current market share for rail freight. However, the rail industry across Europe has plans to increase market share considerably from current levels, for example in the UK the “Value and Importance of Rail Freight” report published by Network Rail anticipates “freight demand to grow by at least 30%; the equivalent of 240 additional freight trains a day, and by as much as 140% over the next 30 years”.

This would result in a significant increase in the numbers of wagons in service over the next 20 to 30 years. When this market share increase is considered along with the number of market countries, then the business opportunity for wagon makers to produce a SUSTRAIL type of vehicle is attractive and should in turn produce a vehicle at much more competitive prices due to high potential unit numbers. This would, in turn, reduce the payback period and drive increased implementation. The technology introduced in the SUSTRAIL intermodal vehicle could also be introduced to other wagon types, perhaps via modularised components such as replacement bogies.

Innovation	Beneficiary	Implementation Timing	Dependencies
Vehicle: Novel running gear	Vehicle Operator	Predicted 2017	New bogie required to accommodate the novel suspension. Prototype testing to be concluded with development to final product.
Vehicle: Axle mounted disc brakes	Vehicle Operator & Infrastructure Manager	Available 2015	New bogie required to accommodate the revised braking system. Training for maintenance techniques and local certification if required. This may be restricted for use only for wholly disc brake equipped trains.
Vehicle: On-board axle box temperature monitoring	Vehicle Operator	Predicted 2017	Power supply and communication to be included in future development. Prototype testing to be concluded with development to final product.
Vehicle: Spring inserts for reduction of structure-borne noise emissions	Vehicle Operator & Infrastructure Manager	Predicted 2016	Known technology for passenger train application. Prototype testing to be concluded with development to final product.
Vehicle: Axle Coating	Vehicle Operator & Owner	Predicted 2016	Development of non-destructive testing process required with associated training and local certification if required.
Vehicle: Wagon wheel set	Vehicle Operator	Predicted 2018	Prototype testing to be concluded with development to final product.
Vehicle: Friction modifiers	Vehicle Operator & Owner	Predicted 2017	Friction modifier testing to be concluded with development of dispensing system.
Vehicle: Aerodynamic fairings	Vehicle Operator	Predicted 2016	Prototype testing to be concluded with development to final product.

Table 4.7

Vehicle innovations

The infrastructure innovations are considered in Table 4.8. All are considered suitable for implementation, although a number will require further development. None of these infrastructure innovations have any dependencies that would prevent introduction individually as soon as they are ready and they do not have any interface issues with existing infrastructure. A good example of this is Premium Rail Steel; there are already multiple materials in use for rail and joining these materials together is included in the development process. The key barriers to implementation are generally the development of maintenance and inspection techniques, training packages and approval/certification.

Innovation	Beneficiary	Implementation Timing	Dependencies
RAIL: Premium rail steel (plain line)	Infrastructure Manager	Available 2015	Training for welding techniques and local certification if required.
RAIL: Premium rail steel (S&C)	Infrastructure Manager	Available late-2015	Development of welding repair techniques and local certification if required.
RAIL: Fatigue life prediction	Infrastructure Manager	Predicted for 2018	Further development of model and verification required.
RAIL: Effect on track forces by changing rail profile	Infrastructure Manager	Predicted for 2016	Training for welding techniques and local certification if required.
EARTHWORKS: sensor in geo-textiles	Infrastructure Manager	Available late-2015	Installation of the sensor-embedded geo-grids requires extra care compared to normal geo-grids in order to prevent failure of the optical fibre
RAIL: Impact of inspection and monitoring technologies (with MerMec).	Infrastructure Manager & Train Operator	Available 2015	Development of alarm settings for specific vehicles and routes.
RAIL: Switch lubrication testing	Infrastructure Manager	Available 2016	Environment testing facility to be procured to extend testing temperature range (2016 on)
RAIL: Smart Washer	Infrastructure Manager	Predicted 2018	Prototype testing to be concluded with development to final product.
RAIL: Rail Fastening Device	Infrastructure Manager	Predicted 2017	Prototype testing to be concluded with development to final product.

Table 4.8
Infrastructure innovations

4.8.2 HUMAN FACTOR ISSUES

In addition to the technical issues, a further set of work was to assess and quantify how much the SUSTRAIL innovations impact on the rail transport industry in terms of personnel needs. This is necessary in order to establish if the project is convenient and desirable for the society as a whole.

The analysis of phasing issues of SUSTRAIL innovations on vehicles and tracks is built through the definition of a business model and the assessment of impacts. One particular aspect includes the identification and the assessment of human factor issues, such as:

- the impacts of SUSTRAIL innovations on vehicles and tracks on human aspects of the rail freight operations, (maintenance, inspection and other train handover activities)
- key barriers for implementation of the designed innovations that may be brought by human factors during the phasing of the introduction of innovations

The analysis was developed in two steps. The first step of the process was completed during 2013, and consisted, after a literature review, in a first round of interviews, discussing with relevant stakeholders the possible impacts of a provisional list of innovations. This permitted researchers to elaborate a final list of questions and to calibrate the interviews in order to produce relevant results in the general context of the project. It was agreed to focus the interviews on two main innovations on vehicles and tracks that are close to being realised in the final phase of the project.

Some activities and dimensions are more affected by the SUSTRAIL innovations than others: maintenance activities (rail replacement, track inspections, transition management, ballast screening, tamping etc.); inspections (time needed for inspections, and personnel needs); ergonomics of the maintenance agents (e.g. working positions, hot/cold conditions, dangerous locations), and the skills of the agents with consequent training required. This list represents the starting point for the analysis of the human factors variations determined by the implementation of the SUSTRAIL innovations.

The outcome of the interviews gave useful provisional insights on the impacts of SUSTRAIL innovations on human factors. In particular, **the effort for maintenance and inspection will decrease**, but it is not possible to quantify or to assess homogeneously the magnitude. The results of the interviews reflect the expectation of a **decrease in track and vehicle maintenance efforts**. In fact, this area is expected to benefit most from SUSTRAIL innovations in terms of a decrease in human factor related costs. **Regarding track maintenance activities, cost decreases are expected for several tasks due to a decrease in the frequency and an increase in automation. In general, manual work tasks are expected to decrease due to the implementation of SUSTRAIL innovations, in particular the need for walking along tracks.** For several track and vehicle inspection and maintenance tasks, the experts expect a change in demand for the handling of machinery and for different skill sets to be required, such as an **increase in engineering and technical skills, and skills associated with computer and digital systems**; training activities to accompany the introduction of SUSTRAIL innovations are expected to be needed.

As an example of the output, the following images summarize the main results of the questionnaire for the premium rail steel. It has to be underlined that results are adjusted in order to show the main output of the questionnaire. If there was no unequivocal output the result followed the majority.

Maintenability	Frequency	Automation	Costs	
	Decreased	Unchanged	Decreased	
	3	1	2	
Inspectability	Safety	Efficiency	Costs	Frequency
	Unchanged	Unchanged	Unchanged	Unchanged
	2	2	2	2
Accessibility	Efficiency	Costs		
	Unchanged	Unchanged		
	3	2		
Ergonomic	Working position	Dangerous Location		
	Unchanged	Unchanged		
	3	3		
Handling of maintenance tools	New Tools	New Machinery		
	Unchanged	Unchanged		
	3	3		
Skills	Training	New Personnel	Qualifications	Costs
	Increased	Unchanged	Increased	Unchanged
	2	1	3	1
Maintenance strategy	Frequency	Costs	New Planing	
	Unchanged	Unchanged	Unchanged	
	1	1	2	
Safety	Global safety	Accidents	Delays	Health conditions
	Increased	Decreased	Decreased	Unchanged
	2	2	2	2

Figure 4.10
Premium Rail Steel: intensity of the results

Maintenability	Frequency	Automation	Costs	
	Decreased	Unchanged	Decreased	
Inspectability	Safety	Efficiency	Costs	Frequency
	Unchanged	Unchanged	Unchanged	Unchanged
Accessibility	Efficiency	Costs		
	Unchanged	Unchanged		
Ergonomic	Working position	Dangerous Location		
	Unchanged	Unchanged		
Handling of maintenance tools	New Tools	New Machinery		
	Unchanged	Unchanged		
Skills	Training	New Personnel	Qualifications	Costs
	Increased	Unchanged	Increased	Unchanged
Maintenance strategy	Frequency	Costs	New Planing	
	Unchanged	Unchanged	Unchanged	
Safety	Global safety	Accidents	Delays	Health conditions
	Increased	Decreased	Decreased	Unchanged

Figure 4.11
Premium Rail Steel: main results

4.9 CHAPTER SUMMARY

Overall the Business Case for the SUSTRAIL innovations is positive. Importantly life cycle costs for both the infrastructure managers and freight operators fall. There are also substantial environmental and freight user benefits derived from modal shift from road due to the cost, reliability, and speed improvements of the revised rail freight offering. For the UK route, there is predicted to be approximately 10% increase in the rail container market, as a result of the track and vehicle innovations.

The role of access charges is clearly important for incentivising the take up of innovations (particularly the vehicle innovations). In addition, a reduction in the capital cost of the SUSTRAIL vehicle is likely to be required for a commercially acceptable payback period to be achieved over what is currently forecast in the LCC analysis. This is reasonable given the early stages of development of the innovations; it can be expected that, as the innovations progress from research through development to the mass-production phase, capital cost will fall. Thus, these innovations should proceed to the commercialisation stage for further optimisation and exploitation.

ROLLING STOCK INNOVATIONS



5 ROLLING STOCK INNOVATIONS

The specific aims of SUSTRAIL Workpackage 3 ‘The freight train of the future’ were to “*identify the key areas where recent and imminent developments can lead to improved running behaviour of railway vehicles resulting in reduced system maintenance and operating costs for vehicle and track, reduced environmental impact and greater sustainability and efficiency*”

5.1 INTRODUCTION

A summary of the work on SUSTRAIL vehicle innovations is presented in this chapter. Input to the workpackage was supplied through deliverables produced during the ‘Benchmarking’ and ‘Duty requirements’ workpackages. This provided specific performance requirements which the SUSTRAIL vehicle will need to meet. Broader requirements and the contextual landscape were also considered through documents such as:

- European and National vehicle and system standards
- European rail sector’s shared high level rail vision set out in ‘Challenge 2050’
- UK’s ‘Rail Technical Strategy 2012’
- ‘5L’ (Low noise, Lightweight, long-running, Logistics capable, LCC-orientated) future initiative white paper ‘Freight Wagon 2030’ published by a consortium of German companies and academics

The work was split into three stages: a ‘Technology review’ which aimed to collect information on all existing and potential innovations that could be incorporated into the SUSTRAIL vehicle design; a ‘Concept design stage’ which matched the innovations against the duty requirements and produced the basic concepts for the SUSTRAIL vehicle; and a ‘Detailed design stage’ which took the concept designs and refined and optimised them using computer simulation and other techniques. These were then coordinated into a series of final designs that were used to build the SUSTRAIL demonstrator vehicle in the ‘Technology demonstrator’ workpackage.

5.1.1 THE SUSTRAIL TECHNOLOGY REVIEW

More details in deliverable D3.1

Lead partner: HUD

The technology review considered most aspects of relevant freight vehicles (including design of bogie subsystems such as suspension, structures, and wheelsets), and the traction of freight locomotives; See Table 5.1. A large number of potential innovations were identified, many of which would give significant potential benefits. A selection process was then undertaken involving all workpackage partners. The selection procedure used the performance requirements identified earlier in the project to produce an overall weighted priority index (WPI) for each of the innovations. On the basis of these scores key innovations were selected and concept designs produced for the SUSTRAIL demonstrator vehicle. Other high-scoring innovations became the subjects of simulations or lab tests: “virtual demonstrators”. For each of the key innovations further work was carried out to refine the design and to select parameters of key components prior to defining the final design for the SUSTRAIL freight vehicle.

Focus area	Innovation	WPI ¹	Demo ²
Running gear	Modified Y25 primary springs	7.40	D
	Rubber springs	6.14	X
	Double Lenoir dampers	6.78	D
	Wedge dampers	6.06	V
	Hydraulic dampers	6.07	V
	High resistance damping material	6.18	D
	HALL bushes	6.12	X
	Pusher springs	6.00	X
	Steering linkages	6.42	V
	Centre pivot stiffness	6.03	V
	Axle coating	7.19	D
	Novel wheel steel	7.14	D
	Novel wheel shape	6.97	D
	Resilient wheels	4.29	X

Table 5.1
Matrix of technology innovations

¹WPI (Weighted Priority Index): Calculated by weighted sum of partners’ assessments. Weights: Compliance with duty requirements (from D2.5), 0.1; Technological benefit, 0.1; Production costs, 0.1; Availability for mass production, 0.15; Reliability, 0.25; Maintainability, 0.175; Sustainability (energy consumption, damage), 0.175

²Demo: (inclusion in SUSTRAIL demonstrator): D, physical demonstrator; V, “virtual demonstrator”; X, not studied

Focus area	Innovation	WPI ¹	Demo ²
Traction and braking	Disc brakes	6.52	D
	Electronic distributor	6.38	D
	Independently rotating wheels	3.58	V
	Use of friction modifier at wheel	5.74	V
	Brake pad with friction modifier	6.35	X
	Traction motor "Induction"	6.51	V
	Traction motor "Permanent Magnet"	6.69	V
	Power electronic drive "Multi level topology M2C"		V
	Power electronic drive "Silicon Carbide SiC"		V
	Energy storage "Batteries"	5.13	V
	Energy storage "Ultra capacitors"	5.66	V
	Medium frequency transformer for AC-grid		V

Focus area	Innovation	WPI ¹	Demo ²
Body and bogie structures	Lightweight bogie based on novel materials	5.78	V
	Lightweight bogie based on hybrid solution	5.99	V
	Lightweight bogie based on shape and components	6.89	D
	Composite bogies	4.94	X
	Aerodynamic fairings	6.22	V
	Light weight body based on novel steels	6.61	D
	Light weight body based on aluminium alloys	6.33	X
	Light weight body based on Composite materials	5.36	V

Focus area	Innovation	WPI ¹	Demo ²
Condition monitoring	Axle monitoring through acoustic emission	6.21	V
	Axle monitoring through vibration measurements and acoustic emissions	7.07	D
	Energy harvesting	6.61	D
	Machine vision technology for monitoring wheels	5.42	X
	Thermal sensors to monitor axle boxes	5.87	D

Footnotes 1, 2 see previous page

It was noted that several of the innovations have been developed to prototype stage in earlier projects, but very few have been incorporated into production freight vehicles. The main reasons behind this were considered to be economic (costs of acquisition, monitoring, and maintenance), with logistical issues of phased introduction and maintenance planning also being relevant. These aspects were considered for SUSTRAIL’s innovations in the business case workpackage.

5.1.2 AXLE LOAD AND SPEED

In discussions between project partners and industry stakeholders the following overall specification was agreed:

1. Axle load: Current axle load limits in Europe are typically 22.5 or 25 t. It is proposed that the SUSTRAIL vehicle will be designed to allow a maximum axle load of 25 t. All structures and components and systems are specified accordingly. It has however been determined that the market for high-value low-density time-sensitive goods is increasing and for this reason it is highly likely that the SUSTRAIL vehicle will very often be carrying loads that do not result in full use of this capacity. For these reasons the SUSTRAIL vehicle will be capable of running at a maximum axle load of 25 t but will have an optional lower loading capacity limit.
2. Speed: Passenger vehicles operate at very high speeds on some parts of the network in many European countries. It is not realistic to expect the SUSTRAIL vehicle to operate at these very high speeds and it must be noted that an increase in speed generally results in an increase in wheel-rail forces and in higher aerodynamic drag and energy consumption. Rates of vehicle and infrastructure damage are often strongly influenced by vehicle speed. However, research has shown that system capacity can be significantly increased if freight trains operate at the same speed as passenger trains. For these reasons it is proposed that the SUSTRAIL vehicle will be capable of operating at 140 km/h when carrying low-density goods but that there will be an optional lower speed limit for the vehicle running at the highest axle load condition.

This overall specification is summarised in Table 5.2.

SUSTRAIL vehicle specification		Max axle load (t)		
		17	22.5	25
Max speed (km/h)	120	YES	YES	YES
	140	YES		

Table 5.2
The SUSTRAIL
vehicle speed and axle
load specification

More details in
deliverables: D3.1,
D2.5

5.1.3 SUMMARY OF THE PERFORMANCE REQUIREMENTS FOR THE SUSTRAIL VEHICLE

Lead partners: HUD,
LEEDS, USFD

SUSTRAIL Workpackage 2 defined duty requirements for the vehicle and infrastructure to achieve potentially double the life of track components when combined with low impact vehicles. The following key requirements were identified:

- With reference to “suspension and running gear” a reduction in damage to the rail and track in terms of derailment; track vertical settlement; rail damage and lateral force is required.
- By having a **combined wheel-slide and brake control system** the SUSTRAIL freight vehicle’s wheels will be in a better condition and will therefore be less damaging to the track.
- Analysis of accelerations and speed requirements showed that currently greater time savings can be obtained by **increasing the speed up to 120 km/h** whilst less benefit can be achieved by increasing from 120 km/h to 140 km/h, mainly due to speed limits imposed by railway crossings, switches, tight curves, and steep gradients.
- Aerodynamics investigations, primarily from the perspective of the associated drag, pointed out a series of options to **improve the aerodynamics of the freight vehicle** and highlighted, for intermodal wagons, the relevant effect of operational factors such as vehicle choice and loading regime.
- Finally with reference to noise mitigation, for the range of operating speeds of the SUSTRAIL wagon, rolling noise will be the dominant source. Since increasing the running speed from 120 km/h to 140 km/h (or higher), will increase the rolling noise, a possible approach is to fit, or retrofit, the wagon with **composite tread brakes or perhaps even disc brakes**.

The identified performance requirements are to some extent conflicting and the SUSTRAIL vehicle design work was aimed at selecting innovations and refining these to provide an optimal solution.

5.2 THE SUSTRAIL BOGIE

More details in deliverable D3.1

The concept design for the SUSTRAIL freight vehicle bogie presented here includes a number of significant innovations in the running gear, wheelsets, braking system, bogie structure and in the adoption of condition monitoring. Despite this, most of the innovations selected are based on proven technology and this reduces the commercial and operational risks and increases the potential reliability and overall chances of success of the SUSTRAIL vehicle. In view of the key requirements of integration of the SUSTRAIL vehicle with the existing fleet and the existing maintenance procedures and safety standards, the WP3 partners took the decision to base the SUSTRAIL vehicle on the well-established Y25 type bogie.

Lead partners: HUD, KTH, SPT, TUB

The primary suspension for a standard Y25 bogie is shown in Figure 5.1. The bogie frame rests on two sets of nested coil springs per axle-box. One of the outer coil springs is connected to the bogie frame via a spring holder and an inclined link (the “Lenoir link”). This link generates a load dependent longitudinal force on the spring holder that is transmitted to the axle-box via a pusher. Thus forces, approximately proportional to the vertical load, are generated in the friction surfaces between the axle-box and the bogie frame. These forces damp motions in the system and address the very large difference between tare and laden vehicle mass and consequent challenge of controlling the dynamic behaviour of the vehicle in both conditions. In the longitudinal direction there is only a 4 mm clearance between the pusher and the bogie frame; once this is exceeded the very high longitudinal stiffness (poor curving properties) causes high levels of damage to track.

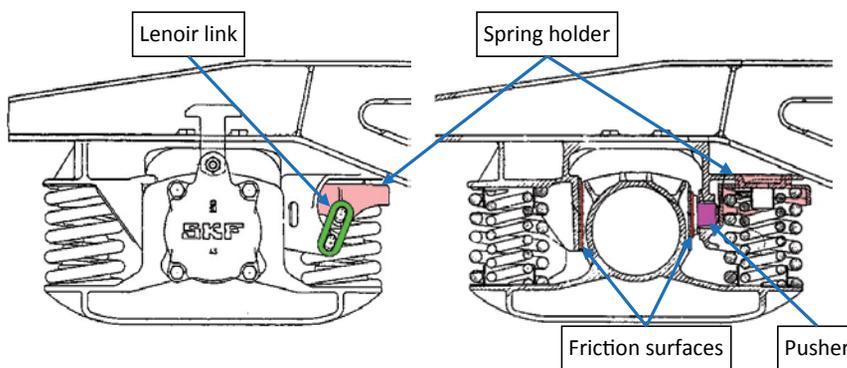


Figure 5.1
Y25 primary suspension

Innovations that would integrate with the Y25 were considered and are described in the following three sections. A summary of the computer simulations follows in Section 5.2.4.

5.2.1 DOUBLE ‘LENOIR LINK’ PRIMARY SUSPENSION

In order to improve curving properties of the system a primary suspension configuration with double Lenoir links (i.e. a link on each of the springs) was chosen for the SUSTRAIL vehicles. With double Lenoir links the longitudinal stiffness of the system is reduced and the maximum longitudinal motion between the axle-box and bogie frame increased compared to a standard Y25 bogie.

5.2.2 LONGITUDINAL LINKAGES

In order to improve the running behaviour of the SUSTRAIL vehicle it was decided to assess the benefit of linkages providing longitudinal and/or lateral stiffness between the axle boxes using a radial arm. This was studied in the Infra-Radial project (see Figure 5.2) which aimed to develop a bogie for heavy haul vehicles (axle loads over 25 t) with reduced life cycle costs.

Figure 5.2

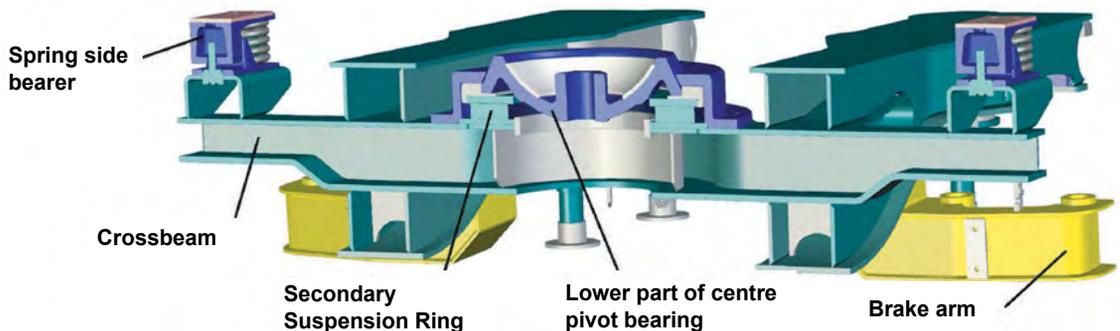
The radial arm as used
in the Infra-radial
project



The Infra-Radial tests using the radial arm with four different primary suspension types showed good results with stable running and radially aligned wheelsets in curves. Wear of the wheels was seen to reduce significantly.

5.2.3 CENTRE PIVOT SECONDARY SUSPENSION

The secondary suspension of the Y25 bogie is realised by a centre pivot bearing and two side bearers. The pivot bearing provides three rotational degrees of freedom. Between the upper part connected to the carbody and the lower part connected to the bogie frame there is a plastic layer with a dry-film lubricant defining the friction and the relative motion without play. The side bearer enables a roll movement between carbody and bogie frame and provides a frictional damping for yaw movements of the bogie frame. Overall, this typical secondary suspension for freight wagons is very stiff in the vertical direction.



The German research program LEILA (an acronym for “light and low-noise rail-freight bogie”) had considered inserting an additional secondary suspension ring between the lower part of the centre pivot bearing and the bogie frame (as shown in Figure 5.3). The goals were to reduce noise levels, peak forces, to improve the comfort level for the goods, to protect the primary suspension from excessive load, and to improve running behaviour. A horizontal bump-stop with 2.5 mm radial clearance was also installed to ensure that the vehicle did not exceed the maximum clearance outline (i.e. remained “in gauge”).

It was proposed that a similar design should be used for the SUSTRAIL bogie; a rubber suspension ring to be mounted between the bogie frame and the car body.

Figure 5.3
Secondary Suspension
of the LEILA bogie

5.2.4 COMPUTER SIMULATIONS

5.2.4.1 COMPARISONS

In order to ascertain that the results of the running gear optimisation are directly comparable and verifiable at the end of the project, an initial benchmark exercise was agreed between the different partners involved in the numerical modelling of the freight vehicle dynamic behaviour. This task was deemed essential because all partners were using different software tools (Vampire, MEDYNA, SIMPACK, and Gensys), modelling techniques and practices, and in order to verify the respective advantage of each technological solution, independent models must behave within a certain tolerance from one another to start with. This also means that in the end, any of the models benchmarked could be used to assess any combination of the technology improvements.

The benchmark concerned the conventional Y-series vehicle model before any technology improvement was added. It was decided to use as a base case the properties of the SGNS wagon used during the EU project DYNOTRAIN, for which parameters (e.g. 14.2 m bogie spacing and 18.5 m deck) and validation data were available. Two configurations were available from the DYNOTRAIN project: empty (4.7 t axle load) and laden (22.5 t axle load). A third part-laden case was derived with a 17 t axle load. The following test cases were carried out to compare the models' behaviour and later to assess the SUSTRAIL vehicle improvements:

- A test of bogie rotation in tight curves to assess the bogie yaw resistance (the “X-factor” is defined as the ratio of yaw torque between the body and bogie to the axle-load multiplied by the wheelbase)
- A test on twist track to determine risk against derailment (the maximum ratio of lateral force to vertical force, $(Y/Q)_{\max}$)
- A test of vehicle stability or critical speed (V_{crit})
- A dynamic performance test aiming to reproduce on-track test results for: a series of curves; at a range of speeds; and for a range of cant deficiencies up to the maximum permissible.

5.2.4.2 OPTIMISATION: LENOIR LINKS AND RADIAL ARMS

Simulations were carried out using MEDYNA for a vehicle with double Lenoir links both with and without radial arms. In these simulations wagon movement was simulated on a straight track with irregularities positioned at the distance of 40 m from the start with velocity reducing from 160 km/h to 40 km/h. The critical speed was assumed to have been reached when the total lateral force ($\sum Y$) dropped below 2.5 kN. A typical example of such simulations is shown in Figure 5.4 (results from the corresponding Gensys simulation).

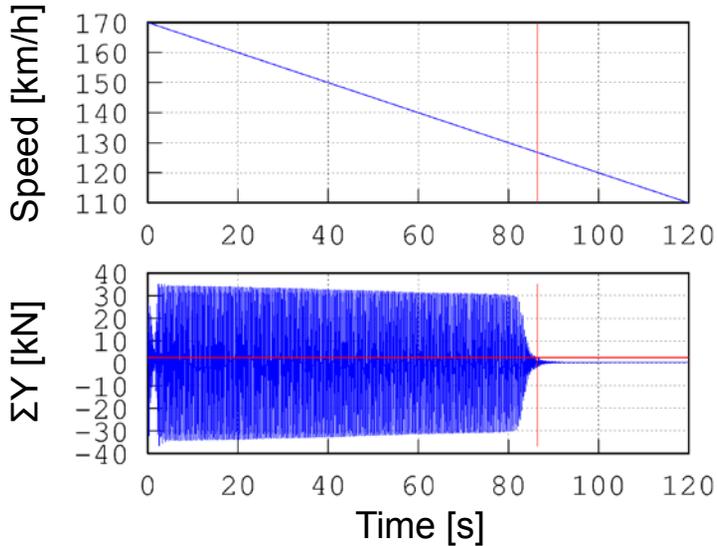


Figure 5.4

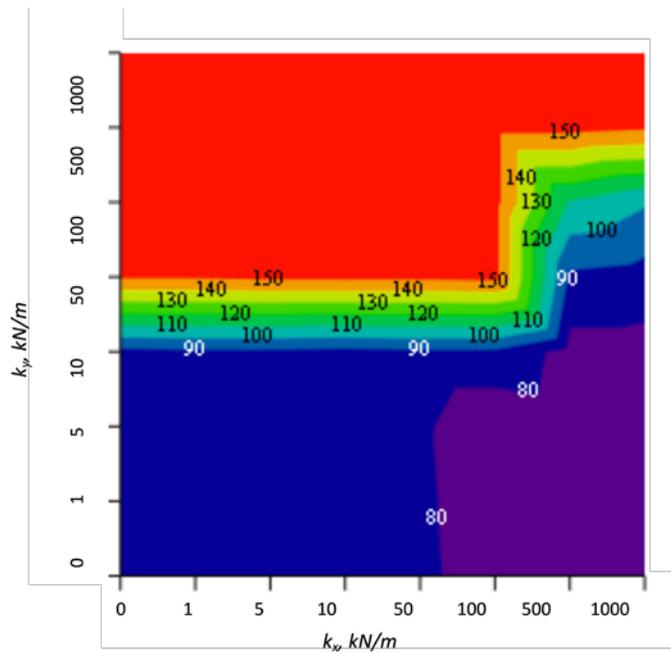
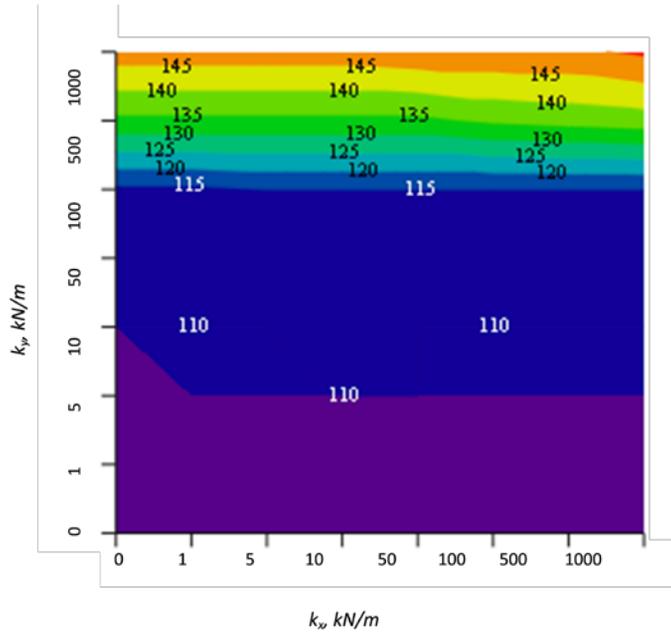
Sample simulation results showing the establishment of the critical speed for the SUSTRAIL vehicle with double Lenoir links

Diagrams of the dependence of critical speed for laden and empty (tare) wagons on the longitudinal (K_x) and lateral (K_y) stiffness of radial arm are presented in Figure 5.5. Analysing the results showed that:

1. The critical speed for a laden wagon without radial arms is 107 km/h and for a similar empty wagon it is 80 km/h.
2. The highest critical speed (not less than 140 km/h) can be achieved by the following stiffness of radial arm:
 - » laden wagon: K_y more than 750 kN/m (critical speed of laden wagon is almost independent of longitudinal stiffness K_x)
 - » empty wagon: K_y more than 40 kN/m and K_x not more than 250 kN/m or K_y and K_x both more than 250 kN/m
3. To achieve a critical speed of 140 km/h for the wagon (for either loading condition), the radial arm should provide 750 kN/m of lateral stiffness. It need not provide any longitudinal stiffness.

Figure 5.5

Diagram of critical speed for laden wagon with 22.5 t axle load (upper), for empty wagon with 4.69 t axle load (lower)



As part of the optimisation of the primary suspension the following parameters were varied, as illustrated in Figure 5.6:

- The vertical coil spring stiffness, k_z
- The ‘angle’ of the Lenoir link, longitudinal offset between ends, A
- The length of the Lenoir link, L
- The friction coefficient at the sliding surfaces (through changing material), μ_{yz}
- The vertical clearance to the bump stop, d_{z0}

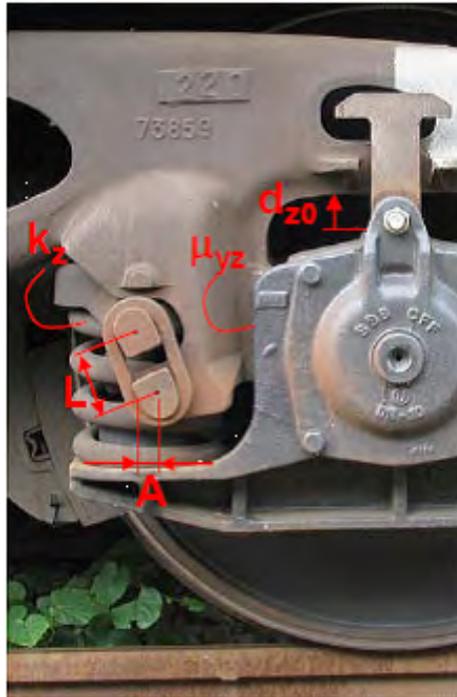


Figure 5.6

The Lenoir link showing the parameters varied in this work

A model of the SUSTRAIL vehicle was set up with double Lenoir links using the computer simulation tool Gensys and the influence of variations in the suspension parameters on the critical speed of the wagon was simulated. Straight track was used for this simulation with an initial lateral disturbance followed by ideal track with no irregularities. The axle load was 22.5 t, wheel profile S1002, and rail profile UIC60 inclined at 1:40. The wheel-rail coefficient of friction was set at 0.35. Results from one of these simulations, reducing from an initial 170 km/h were shown in Figure 5.4.

The effects of the various suspension parameters on the critical speed are shown in Figure 5.7.

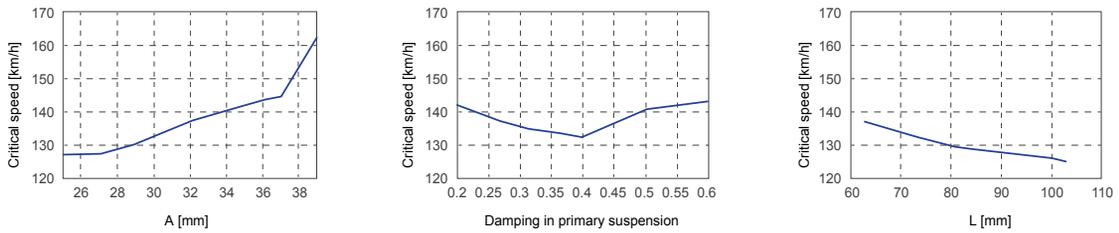


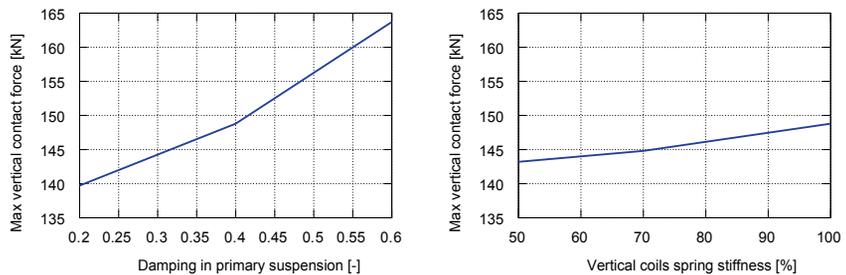
Figure 5.7

The effect of Lenoir link angle, friction coefficient, and length on the critical speed of the SUSTRAIL vehicle

Further variations were carried out and the effects of the friction coefficient and stiffness within the suspension on the maximum contact force are shown in Figure 5.8.

Figure 5.8

The effect of friction coefficient and spring stiffness on the contact force



It can be seen that the maximum vertical contact forces tend to increase with the coefficient of friction and with the spring stiffness.

5.2.4.3 OPTIMISATION: CENTRE PIVOT

The simulation tool Simpack was used to investigate the effect of varying the stiffness of the centre pivot. The simulations were carried out on straight track with sinusoidal inputs to excite: bouncing (in-phase vertical irregularities on rails), rolling (anti-phase vertical irregularities on rails), hunting (lateral excitation of bogies), and yawing (in-phase lateral irregularities on rails). The results showed that higher pivot stiffness was associated with lower amplitudes of vibration, so the standard Y25 centre pivot was retained in the SUSTRAIL vehicle.

5.2.5 THE PROTOTYPE SUSTRAIL BOGIE

Following extensive computer simulations as described above the parameters for the various components of the running gear for the SUSTRAIL bogie were selected. Designs for the longitudinal arms were produced and a prototype constructed by the Romanian manufacturing partner. As a result of the computer simulations it was decided not to adopt the resilient secondary suspension and a standard UIC centre bowl arrangement was instead used for the SUSTRAIL vehicle.

In addition to the innovative suspension, the vehicle has disc brakes with an electronic control system. A CAD model of the bogie design is shown in Figure 5.9.

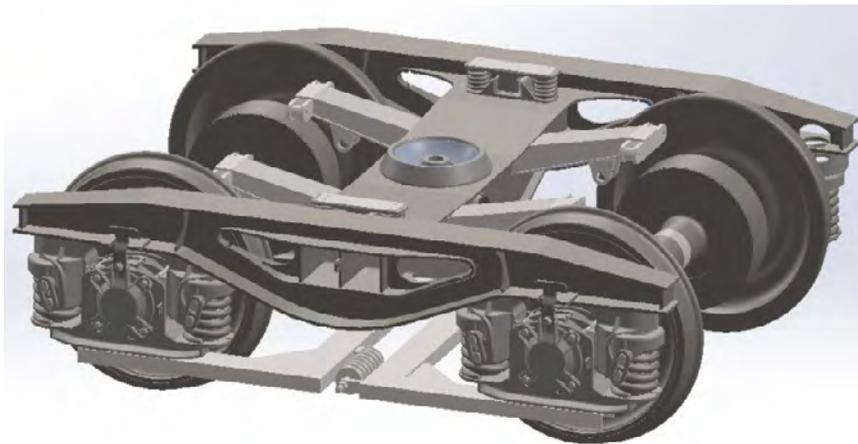


Figure 5.9
The prototype
SUSTRAIL freight
bogie

More details in deliverable D3.1

5.3 AXLE COATING

Lead partners:
LUCCHINI, POLIMI

A new axle coating developed by Lucchini RS, shown on the SUSTRAIL vehicle wheelsets in Figure 5.10, has been selected. The coating provides improved corrosion resistance, compared with traditional coatings, and resists impacts in a wide range of temperatures (-40°C to 150°C). So, it protects the axle and limits the possibility of crack initiation even under aggressive conditions; this can reduce maintenance costs. Although it does not cause an appreciable increase in wheelset mass, the coating will increase the diameter of the axle by about 4 to 5 mm as shown in Figure 5.11.

Figure 5.10
The SUSTRAIL
wheelsets

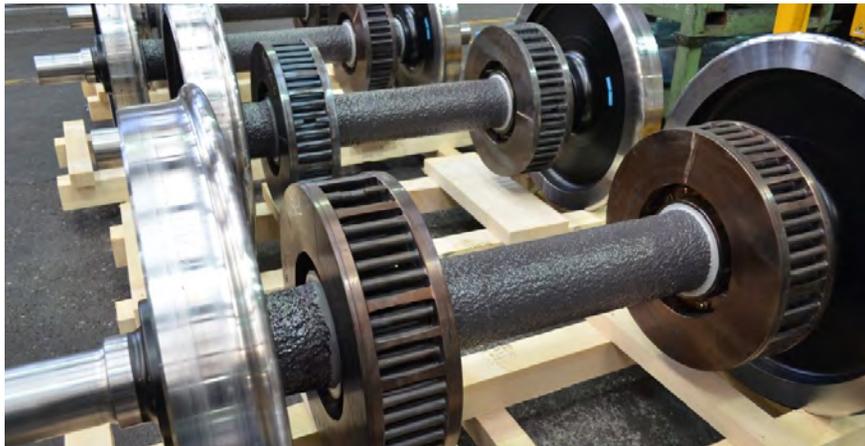


Figure 5.11
Section through the
coating



Currently a typical maintenance plan for freight wheelsets includes a visual inspection (EVIC) every 300,000 kilometres (about 3 to 6 years), and every 600,000 kilometres (6 to 12 years), the following “heavy” maintenance activities:

- wheelset removal from bogie
- bearing dismounting and maintenance
- removal of paint on axle
- MT (magnetic particle inspection for detecting surface defects) of the axle
- UT (ultrasonic inspection) of wheel seats (if wheels are not removed)
- axle repainting and bearing remounting.

The innovative coating allows for a simplified inspection and the sequence of “heavy” maintenance activities becomes:

- wheelset removal from bogie
- bearing dismounting and maintenance
- bearing remounting

It is important to highlight that traditional MT inspections are not applicable since the coating is not removable, while visual inspections are unnecessary for the same reason. The in-service maintenance policy can then be revised based on new inspection intervals just considering UT inspections (e.g. by rotating probes) from the axles’ ends.

5.3.1 BALLISTIC IMPACT TESTS ON COATED AND UNCOATED AXLES

Impact tests were carried out on a series of axle chunks considering different combinations of uncoated, newly coated, and aged coated, at room temperature (nominally 25°C) and -25°C. All combinations were tested following the procedure given in EN 13261 “Railway applications, Wheelsets and bogies, Axles, Product requirements” and also using an aeronautical “rooster booster” firing real ballast stones. For coated axle chunks, the deepest penetration (1 mm) was obtained following a perpendicular impact with an energy of 32.6 J at -25°C (about three times the energy required for EN 13261) and this was adopted as the initial crack depth in the fracture mechanics simulations described in the next section.



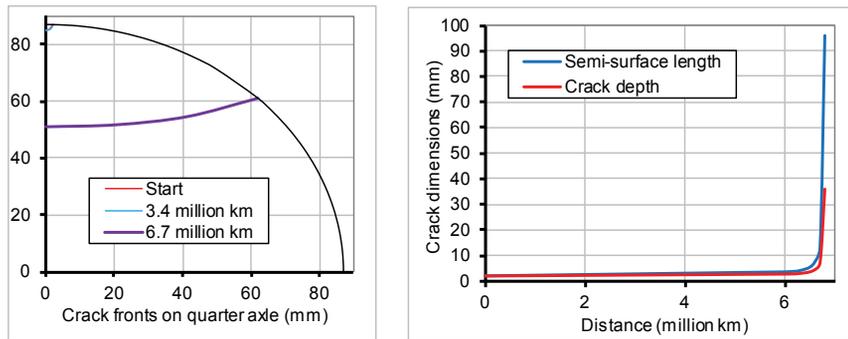
Figure 5.12
Selected results of
ballistic impacts

5.3.2 NON-DESTRUCTIVE TESTING (NDT) INSPECTIONS FOR COATED AND UNCOATED AXLES

In order to estimate the inspection interval, an approach based on fracture mechanics concepts and “Probability of Detection” (POD) curves was adopted.

Service loads, in terms of load spectrum, were firstly determined by means of numerical dynamical simulations taking into account rail geometry, service speed, and rail irregularity. Structural finite element analyses were then carried out in order to derive the stress profile at the T-transition (where the axle diameter increases to accommodate the wheel seat) to take account of both the bending moment due to service loads and the stresses due to press-fit of the wheel. Crack propagation of the material was modelled using NASGRO equations calibrated to fit experimental crack propagation curves derived at different stress ratios during previous research at PoliMi. For the traditional scenario, the starting crack was assumed to have a semi-circular shape with radius equal to 2 mm. It was predicted that there would be a final failure after more than 6 million km at the T-transition for the uncoated axle.

Figure 5.13
Crack growth predictions at the T-transition



The crack growth prediction for the uncoated scenario was used together with probability of detection (POD) curves for UT and MT applied to solid axles. The resulting failure probabilities, P_f , for the standardized inspection interval of 600,000 km, were: $P_f=8.1 \times 10^{-16}$ for UT from the axle-end furthest from the crack and MT; and $P_f=8.0 \times 10^{-22}$ for UT from the axle-end nearest to the crack and MT.

Considering the coated scenario, the initial crack depth of 1 mm (from the ballistic tests described above) is predicted to not grow, so the failure probability drops to zero. However, it is intended that a more rigorous and experimental characteristic initial crack depth for thick-coated axles will be determined as a continuation of the research performed in SUSTRAIL.

5.4 FRICTION CONTROL

More details in deliverable D3.1

The friction coefficient between the wheels and rails has a very significant influence on the behaviour of a railway vehicle. The proper control of friction in the contact zone of the wheel and rail (and, for relevant vehicles, wheel and brake shoe) can play an important role in reducing environmental pollution, vibration and noise, and reducing the cost of operation and maintenance. Friction modifiers can be used to control or vary the friction coefficient in different areas of the wheel and rail and tests of their effectiveness were carried out to establish the potential benefits for the vehicle and track.

Lead partners: GTU

Wheel-rail interaction occurs at: tread surfaces during rolling, traction and braking; steering surfaces (flange and side of rail head) both during curving and when protecting the wheel-set from derailment; and flange root and rail corner which could occur during rolling, traction, braking, or steering. The friction coefficient for wheel-rail interaction can vary between 0.1 and 0.8. The various requirements of the wheel-rail interface are however conflicting with a relatively high value being required for traction and braking (0.25 to 0.4) but a lower value being desirable in flange contact to avoid wear. Innovative wheel profiles were considered to address the separation of these friction surfaces.

5.4.1 TESTS OF INTERFACE BETWEEN WHEEL AND RAIL

To assess the capabilities of friction modifiers (FM), tests were carried out on a twin-disc machine, see Figure 5.14. Experimental research was performed during rolling of discs with up to 20% slip (appropriate for flange contact). The wheel and rail rollers had diameters of 40 mm and widths of 10 and 12 mm. A benchmark was provided by testing with the Ukrainian lubricant “AZMOL”. For these heavy loaded rolling/sliding surfaces, scuffing results in the intimate contact of the interacting surfaces.

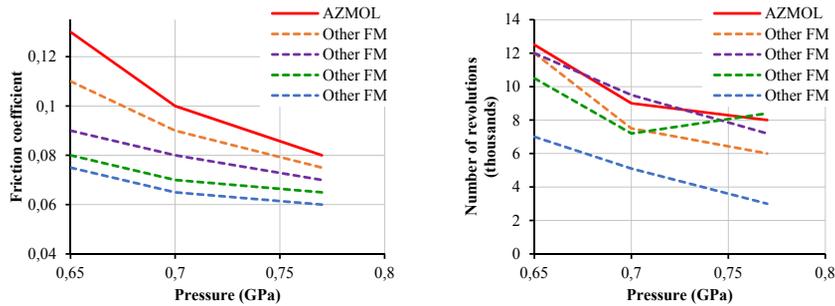


Figure 5.14
Experimental disks on
twin disk machine

The plots in Figure 5.15 show that for the initial linear contact, when the contact stress is in the range 0.65 to 0.77 GPa (flange contact), increasing contact stress leads to decreasing friction coefficient. This is characteristic for solid modifiers. It can also be seen that increasing contact stress leads to a decreasing number of revolutions until the onset of scuffing. The FM developed during SUSTRAIL produce lower friction than AZMOL and for some contact pressures specific ones can last longer before scuffing begins.

Figure 5.15

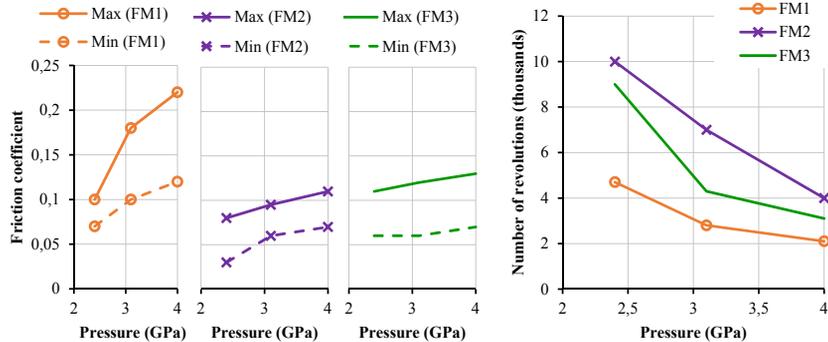
Dependences of friction coefficients, and numbers of revolution till appearance of the first signs of scuffing on the contact stress for initial linear contact of disks



The plots in Figure 5.16 show that, when the contact stress is in the range 2.42 to 3.96 GPa (tread contact) the friction coefficient increases with increasing contact stress.

Figure 5.16

Tread contact: dependences of friction coefficients, and numbers of revolution till appearance of the first signs of scuffing on the contact stress for initial linear contact of disks for 3 different FM



Corresponding results for pressures appropriate to flange contact are presented in Figure 5.17.

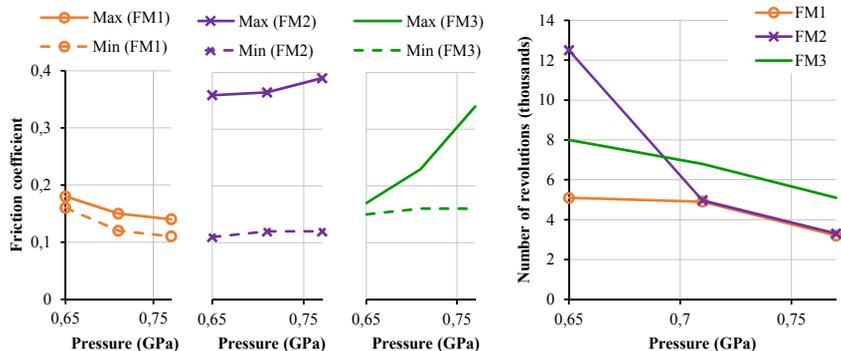


Figure 5.17
Flange contact: dependences of friction coefficients, and numbers of revolution till appearance of the first signs of scuffing on the contact stress for initial linear contact of disks: 1-3: different FM

5.4.2 TESTS OF INTERFACE BETWEEN WHEEL AND BRAKE SHOES

The wheel tread surface is used as the brake drum in many freight cars. In such conditions the FM will affect the interaction between the wheel tread and the brake shoe; the interacting surfaces are protected from direct interaction by the presence of the friction modifier as a “third body”. This reduces the maximum shear stresses and distributes the contact pressure more evenly, thus decreasing the rate of damage.

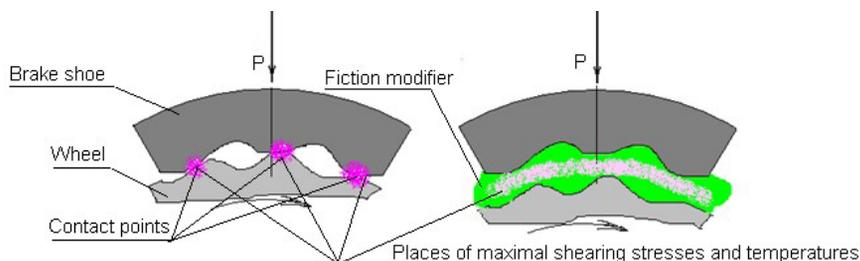


Figure 5.18
Interaction of the brake shoe and the wheel with and without FM in the contact zone

The preliminary experimental tests of friction between wheels and brake shoes were performed using one disk of the twin disk machine being a wheel of st45 steel and specimens of wagon brake shoes being pressed against it, see Figure 5.19. The rotating speed was 1,000 rpm and contact pressure varied between 1 and 2 MPa.

Figure 5.20 shows dependences of friction coefficient and wear rate on loading for brake shoes. It can be seen that using this friction modifier causes the friction coefficient to reduce by 20 to 30% compared to a “dry” interface. The friction coefficient is in the range 0.38 to 0.63. However, wear rate decreased by between 2 and 3.5 times at 2000 revolutions. In these preliminary tests several factors were not considered including: the scale coefficient, the overlap factor, the area in contact with ambient.

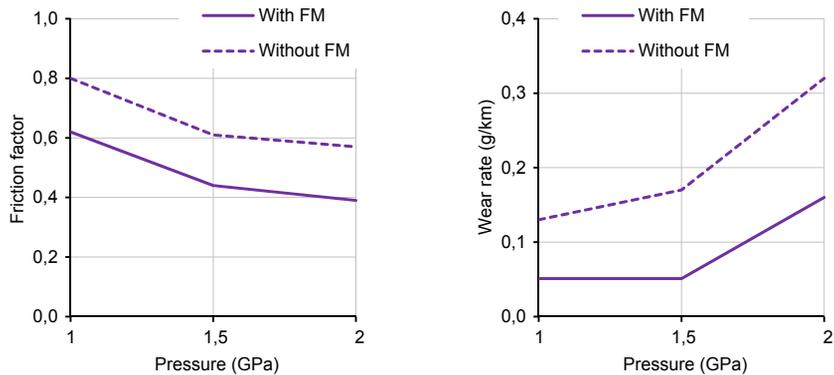
Figure 5.19

Disk and brake shoe on twin disk machine



Figure 5.20

Dependences of friction coefficient and wear rate on loading



5.4.3 FRICTION MODIFIER CONCLUSION

The laboratory research has shown the satisfactory properties of the tested FM for interacting surfaces of wheel and rail and wheels and brake shoes. The operating ability must be determined by field tests.

5.5 BRAKING

More details in deliverable D3.3

The braking system, as with the rest of the SUSTRAIL vehicle, aims to use recent and imminent innovations to produce an innovative high performance freight vehicle to allow the vehicle to function at an increased speed of 140 km/h while still delivering reduced impact and greater efficiency to allow the market needs to be met.

Lead partner: KES

This section describes the architecture of the combined wheel-slide protection and brake control system with comprehensive diagnosis functionality for modern, innovative freight cars.

5.5.1 ARCHITECTURE OF THE BRAKING SYSTEM FOR THE SUSTRAIL VEHICLE

The system used for this project is a combined system containing brake control and wheel-slide protection functions due to the required basic conditions. For improved availability and safety, these functions use separate components. Similarly, redundancy was designed into crucial functional units of the brake control.

The architecture of the braking system for this project was thus divided into the following four sections:

- Vehicle components such as bogie and brake equipment, air reservoirs, etc.
- Brake control, controller, and pneumatic components for the activation of the brake cylinder
- Wheel-slide protection with axle-rotation speed measurement and dump valves
- Independent and reliable power supply for the control devices in the vehicles with axle generator and battery pack.

An overview of all main components designed into the new brake system is given in Figure 5.21.

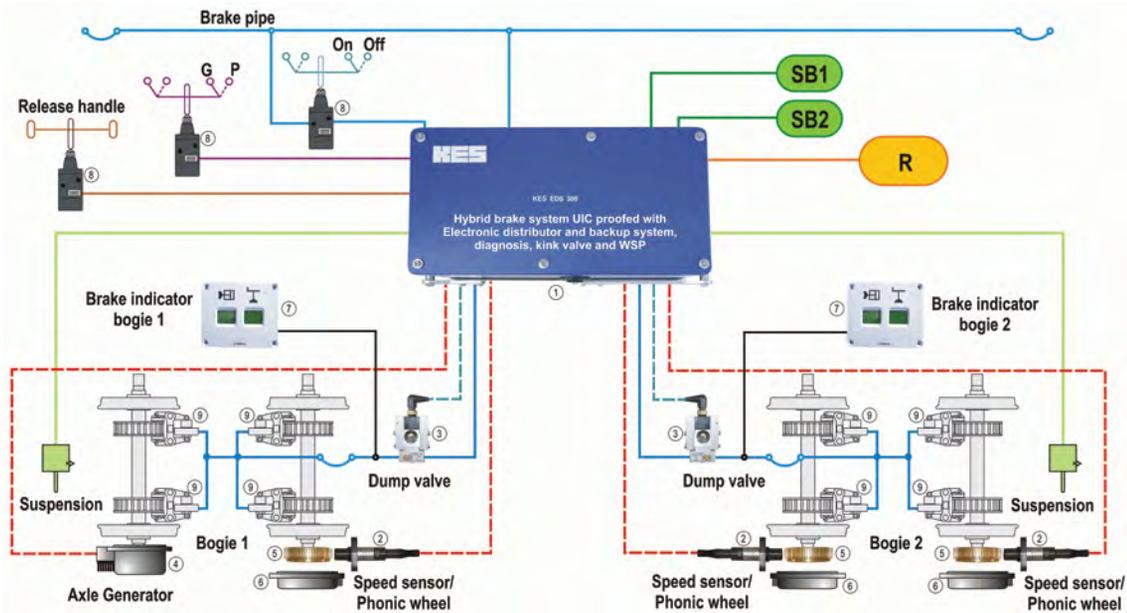


Figure 5.21
The SUSTRAIL
electronic braking system

5.5.2 BRAKE DISCS, PADS, AND CYLINDERS

Due to the performance characteristics required, the SUSTRAIL vehicle was equipped with two brake discs per axle. The disks and the brake pads used were designed in accordance with the brake calculations. The brake cylinders and brake leverage were selected in accordance with the disc brake device applied; one compact (10" or less) brake cylinder was used for each brake disc.

5.5.3 WEIGHING VALVE

For the local detection of the load condition, two weighing valves needed to be installed in the bogie. The type of weighing valve was set to "type 1" according to UIC bulletin 541-04, appendix B "Characteristics of weighing valves".

5.5.4 ELECTRO-PNEUMATIC CONTROL (ELECTRONIC DISTRIBUTOR)

An electro-pneumatic control calculates and sets the brake cylinder pressure using the brake pipe pressure and the actual load measurement.

This control fulfils the entire functionality according to the relevant UIC bulletins. Moreover, it contains comprehensive diagnosis functions typical for modern control systems. It is possible to monitor the functioning of all components of the brake control continuously and without external interaction and thus to identify and warn of possible failures. The diagnosis function integrated into the brake control forms the basis for effective maintenance and cost-optimized operation. The system also tests the brakes before departure.

5.5.5 PNEUMATIC BACKUP SYSTEM

To ensure that the system is fault tolerant, it must include a redundant, purely pneumatic backup system. Therefore, the pneumatic backup brake system, proposed for the SUSTRAIL project is able to take over the main functions in the brake sector automatically should the electronic control fail. In this way, not only is the safety in a major part of the brake control doubled, but also maintenance intervals can be extended thus reducing the operating costs of the vehicle.

5.5.6 WHEEL-SLIDE PROTECTION

Due to the high speeds which are required to be achieved by the SUSTRAIL vehicle, the use of brake discs, and due to the increased requirements with regard to minimization of wear and damage a wheel-slide protection system is included.

The wheel-slide protection control has been implemented at the axle, in order to reach optimum performance and is integrated with the electronic distributor. The wheel slide-protection system designed for this project is completely independent from the brake control for safety reasons and involves speed measurement by means of speed sensors with rectangular outputs. This calculates the vehicle reference speed and monitors the sliding on each axle. If necessary, dump valves mounted on the car body near the brake cylinder are applied.

5.5.7 POWER SUPPLY

The brake system and wheel-slide protection system depend on a reliable power supply. For a freight wagon without a permanent power supply the power can be generated by an axle generator with a set of back-up batteries, although an external connection for a power supply could be provided. All electrical components were optimized with regard to power consumption and had an intelligent power management system to reduce the environmental impact.

The system voltage for all electronic units is $24V \pm 30\%$. Dump valves and pneumatic units can have other internally generated nominal voltages or show minor tolerances.

5.6 NOISE REDUCTION

Lead partner: TUB

A key requirement for the SUSTRAIL bogie is that it has low noise emissions. This section summarizes the work done on noise reduction in this project.

5.6.1 BACKGROUND

There are many sources of noise from trains but the main problem for the target speed range is rolling noise. The roughness of the contact between wheels and rails excites vibrations of wheels, rails and sleepers. These vibrations are transmitted to the surrounding air as radiated sound. Rolling noise is characterized through different frequencies of the wheel, rail and sleeper. Since the human ear is very sensitive to frequencies around 1000 Hz, noise reducing measures at the wheel and the rail are the best options to reduce noise emission. As well as the noise emission of wheel and rail, further components of a freight wagon like brake rods, springs, bogie frame and car body frame, can have an influence on the noise emission.

In the study “Burden of disease from environmental noise: Quantification of healthy life years lost in Europe” the World Health Organisation sees traffic noise as the second largest health hazard after air pollution. Cardiovascular diseases, cardiac infarction, insomnia, stress and tinnitus are common human diseases associated with high sound levels at night. It was estimated that about one in every five people has insomnia caused by traffic noise. However, the study reported that railway noise is less disturbing than road traffic noise.

5.6.2 ECONOMIC AND LEGISLATIVE MEASURES

One possible use of the “Directive 2001/14/EC of the European Parliament and of the Council of 26 February 2001 on the allocation of railway infrastructure capacity and the levying of charges for the use of railway infrastructure and safety certification” could be the use of noise-related track access charges. This measure is implemented in Netherlands, Switzerland, and Germany; new more-restrictive track access charges seem to be realistic. The noise-related track access charges can be divided into “bonus” (rebates for quieter vehicles) and “malus” (financial penalties for noisier vehicles) systems. Each system has advantages and disadvantages and they can be combined.

Every new or renewed freight wagon has to keep the pass-by noise values, listed in the EU’s TSI: “Technical specifications of interoperability relating to the subsystem ‘rolling stock – noise’ of the trans-European conventional rail system”. With these limiting values it is possible to prohibit new, noisy freight wagons.

5.6.3 NOISE REDUCTION ARRANGEMENTS ON BOGIES

In Table 5.3, a summary of the most important measures for noise reduction of bogies is given. It can be seen, that the largest effects are possible by changing the braking system (as mentioned in Section 5.5). Noise protection skirts for bogies are also a good choice, but there are some issues with maintenance and operation. The noise protection skirts for wheelsets (mounted on the bogie) are less effective, but in combination with low-level noise barriers become as effective as noise-protection skirts for bogies.

Optimized webs for wheels seem to have a good noise reduction potential. A disadvantage is that the easiest method, a straight web, works only with disc brakes and a new homologation for the wheelset would be required. An easier method to reduce the noise emission of the wheel is the use of wheel noise absorbers; there are several suppliers and a separate homologation is not required.

Measure	Noise reduction potential [dB(A)]
Compound brake shoes: K-block	10 (compared to cast iron brake shoes)
Compound brake shoes: LL-block	10 (compared to cast iron brake shoes)
Disc brakes	2 to 3 compared to K-block
Wheel noise absorber/ Hypno® Damping System	10 to 15 (curve squealing)
	1 to 5 (rolling noise)
Coated wheelsets/bogies	1 to 2
Wheels with noise optimized webs	2 to 6
Noise protection skirts for wheelsets	2 (higher values in combination with low-level barriers are possible)
Noise protection skirts for bogies	About 10 (absorbing material inside)
Viscoelastic suspension	2 (no curve squealing)
Spring inserts	Unknown

Table 5.3
Summary of the most important noise reduction measures for bogies

Note that it is not possible to use the data in Table 5.3 to quantify the noise reduction associated with multiple measures. For every new bogie concept, with more than one of the listed measures, separate measurements are necessary.

To reduce noise emissions, the SUSTRAIL bogie uses disc brakes, and spring inserts.

More details in
deliverable: D3.4,
D3.5

Lead partners:
UNEW, UVA

5.7 VEHICLE STRUCTURE

The SUSTRAIL project aimed to develop the outline design of an innovative intermodal flat wagon that would respond to increased flows of intermodal loading units, which include ISO containers, swap bodies and semi-trailers, and was flexible and adaptable for other commodities, as well.

The SUSTRAIL vehicle upgrades focused on three criteria:

1. Lightweight design (bogie, frame, overall structure)
 - » Materials selection
 - » Hybrid Solutions (shape, components, dimensions and materials)
 - » Structural design (shape and components)
2. Increased capacity
 - » Greater and more flexible payload
 - » Improved availability
 - » Multi-functionality (different commodities)
3. Sustainable, low cost solutions
 - » Interchangeable and inexpensive components and parts (couplers, wheelsets, buffers, etc.)
 - » Sustainable materials (e.g. recyclable or recycled)
 - » Reduced maintenance

5.7.1 SELECTION OF INNOVATIONS

The innovative wagon concept addressed the following challenges:

- Lightweight structural solution
- Multi-purpose and flexible structure
- Modular design
- Commonality and interoperability
- Sustainable engineering solutions (in relation to materials, design, and manufacturing)

The design process was guided by the project objective of increasing overall tonnage throughput. The vehicle outline design, including the detailed designs of its structural parts, considered the following crucial inputs:

1. The innovative concepts relating to the key challenges for SUSTRAIL freight wagon (i.e. lightweight, multi-purpose, modular, flexible and sustainable)
2. The duty requirements, specifications, and recommendations from previous work
3. The boundaries defined by standardisation, regulation, and manufacturing capabilities

Consequently, various innovative technologies, materials, and designs were selected for possible inclusion in the SUSTRAIL freight wagon. After some analysis the list of proposed innovative solutions was refined and the final selected upgrades and subsequent activities are summarised in Table 5.4.

Solution / task	Main objectives
Optimisation of wagon length and disposition of spigots	Increase capacity (efficiency)
Novel steel products for lightweight vehicle structure (wagon and bogies): » steel grades (i.e. high strength steels) » novel profiles (e.g. cold formed)	Lightweight
Side walls » construction options/stanchions » material: light composites, etc.	Increase capacity (efficiency), lightweight
Floor from recycled / recyclable materials (e.g., polymers)	Increase capacity (efficiency), costs, lightweight, recyclability
Tarpaulin cover	Increase capacity (efficiency), lightweight
Selection of components: based on TSI and commonality (buffers, coupler, bolster, etc.)	Cost-efficiency, low maintenance
Lightweight aerodynamic fairings (e.g. composite)	Environment (noise)
Integration of monitoring systems	Increase performance, low maintenance

Table 5.4
Summary of
SUSTRAIL freight
wagon upgrades

5.7.2 ESTIMATED BENEFITS

- Increased payload (as a result of overall vehicle mass reduction)
- Increased flexibility
 - » *Improved configuration enabling optimised loading with various containers (different sizes and weights)*
 - » *Improved capacity for transport of other commodities (as a result of the flexible modular design)*
- Improved sustainability (i.e. environment-friendly and cost-efficient solutions)
- Improved interoperability and maintenance

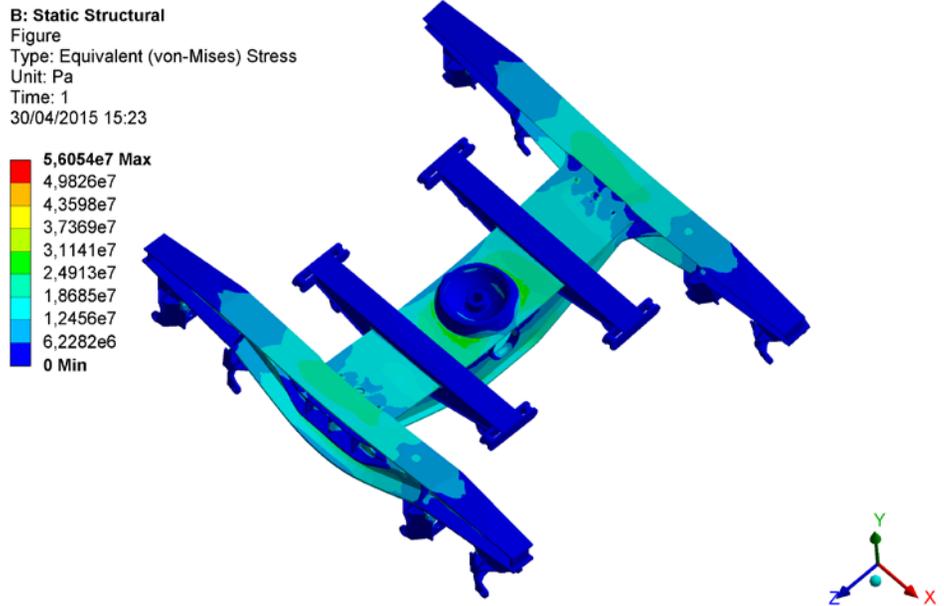
5.7.3 BOGIE FRAME

The bogie frame was modified to enable the implementation of the innovations relating to the running gear and braking system. It consisted of a welded structure, comprising several parts, as shown below.

The main structural modifications required by the implementation of SUSTRAIL innovative solutions included:

- Removal of front and rear transverse beams: these beams were necessary to support the tread brakes in the original design and are not required by the disc brake system
- Addition of support components to the central main transverse beam to attach the levers of the brake discs' actuators
- Strengthening of the central main transverse beam to resist the supplementary forces generated by the braking system

Figure 5.22
SUSTRAIL modified
bogie frame



The new bogie frame was designed with respect to the following requirements and objectives:

1. To enable the installation of innovations relating to the running gear and braking system
2. Lighter-weight than the original Y25 frame, through an optimised design using sustainable and available material solutions
3. Structural strength to comply with SUSTRAIL vehicle specifications (increased payload and/or speed)

5.7.4 VEHICLE BODY

The innovations introduced in the vehicle body are summarized in Figure 5.23.

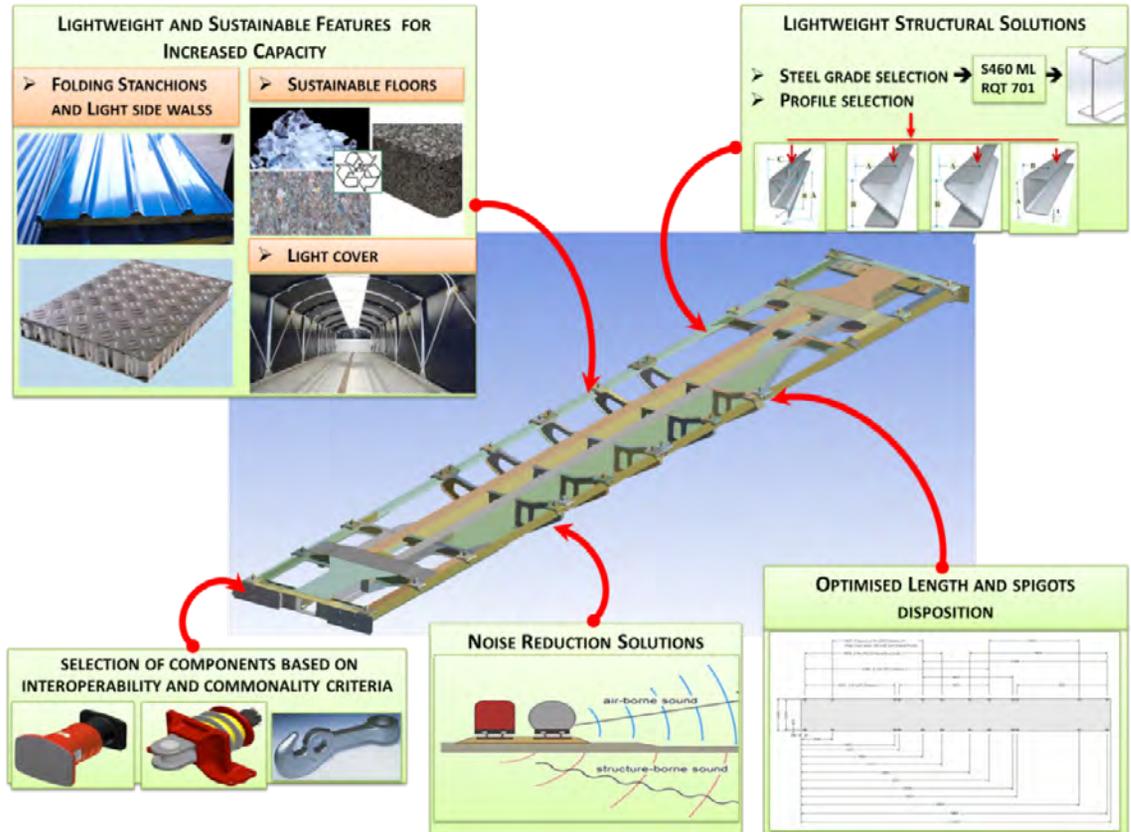


Figure 5.23
SUSTRAIL intermodal flat wagon concept

5.8 AERODYNAMICS

Lead partner: USFD

Aerodynamic drag is approximately proportional to the cube of the vehicle speed, so as freight trains move faster it will become more important. A review of options for reducing aerodynamic drag was undertaken, but no design changes were undertaken:

- **Smooth sides and top:** by streamlining the strengthening ribs on the exterior of freight wagons a reduction of up to 23% in drag may be achievable. Similar streamlining options for SUSTRAIL vehicles include adding a flat cover on the deck of intermodal wagons
- **Bogie fairings:** designed to reduce the noise associated with the operation of brakes they also reduce drag. However, the reduction was reported to be only about 10% for a high-speed train so is unlikely to be significant for freight.
- **Smooth underframe:** improved air-flow under the vehicle is used for the fastest high-speed trains and achieves a reduction in drag of about 7.5%
- **Covering hoppers:** The aerodynamic drag associated with open hopper wagons can be reduced by adding covers. This has a significant effect on American long-haul, but for typical European journeys the fuel saving is estimated to be only 3%
- **Streamlining the load:** A smooth exterior to containers can reduce drag by 10% and there are patented ‘bolt-on’ fairings for the ends of containers, and curtains between containers. These are difficult to implement as there are effects for the whole supply chain and severe logistical problems to be overcome.
- **Lengthening vehicle:** to better accommodate the expected mix of container sizes expected on certain European routes. On these routes, an eighty-foot vehicle could provide a 14% reduction in aerodynamic resistance compared to a standard sixty-foot one.
- **Reducing inter-vehicle gaps:** close-coupled wagons have been developed having two or three sixty-foot decks with buffers only at the outboard ends. A 10% reduction in drag coefficient is reported.
- **Optimising loading:** (see Figure 5.24) the energy required can be halved by placing containers adjacent to each other instead of leaving gaps.

The energy associated with aerodynamic drag was studied as part of SUSTRAIL. Wind tunnel data was reassessed to enable the effect of wind and loading of containers to be analysed. Typical results are shown in Figure 5.24 where measured train speeds are compared with a nominal run at 120 km/h. It would be economic to run a vehicle with a smooth deck if the energy required to transport the additional weight was less than the aerodynamic energy reduction. For a wagon used 90% of the time and travelling at 120 km/h, the break-even mass is equivalent to a 0.2 mm-thick steel sheet.

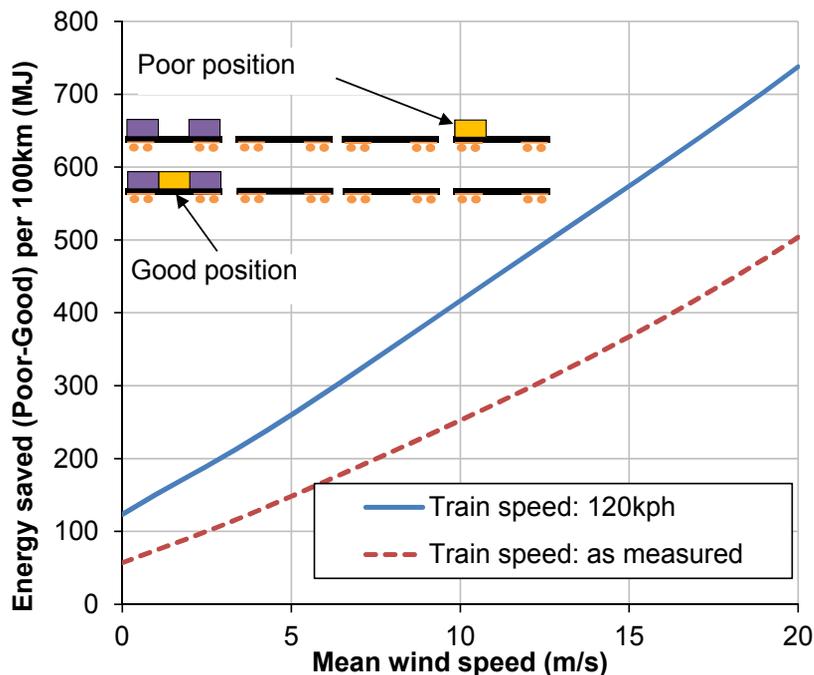


Figure 5.24
Energy that can be saved by optimal positioning of a container

5.9 TRACTION

Lead partner: KTH

Traction is one of the main subsystems of the freight train and consequently the technology has an impact on the operational efficiency of the train. Several traction innovations were considered in SUSTRAIL. A brief overview is provided here.

5.9.1 INTRODUCTION

About 52% of railways in Europe are electrified yet under a diversity of different systems. Both AC and DC systems exist with different voltage levels and frequencies. This is a big challenge for moving freight by rail as locomotives appropriate for each electrification system (and un-electrified track) are needed. Changing locomotives will increase the journey time and put a heavy load on planning and logistics along the chosen transport path. Possible solutions are to have locomotives that are:

- Diesel electric: the diesel output shaft is connected to an electric generator that powers the electric motors
- Genset (generator set): like a diesel electric, but with multiple smaller generators to efficiently cope with differing power requirements
- Dual mode: combining electric (e.g. pantograph) and Genset in one vehicle
- Hybrid: as dual mode, but also including energy storage: batteries, 'super capacitors', or flywheels

The design and optimisation of hybrid locomotives, including optimising different combinations of energy storage devices, is an area of active research. There are many different classifications of hybrid vehicles depending on, for example, whether there is a mechanical connection between the motor and the axle. The expected operating conditions determine which configuration will be best. Some developments were undertaken as part of SUSTRAIL.

5.9.2 DESIGNING THE VEHICLE

One possibility for improving the performance of a vehicle would be to look at how to meet requirements such as acceleration, maximum speed, and maximum torque, then consider other requirements such as maximum weight of the locomotive, efficiency, and cost. Whether higher efficiency can be achieved with a hybrid system depends on the application. Different types of hybrid systems are better for some applications and are less suitable for others and the efficiency of the system strongly depends on the load cycle.

To find out possible benefits of hybridization, the power demand during the vehicle's operation is studied. Variations in power demand from the load cycle will have a direct impact on the size of the energy storage required. There is a significant difference between the locomotive load-cycle when working on the switch yard compared with the load cycle of a long distance freight locomotive. The load-cycle will have a huge impact on the locomotive's fuel consumption. Energy required is given by the integral of the power over a time period, thus in operations with a high frequency power demand (e.g. shunting) the required energy storage will tend to be smaller than that for slowly varying cycles (e.g. haulage). These studies, however, are based on a well-known, or well defined, load cycle. In reality this may not be available; if load cycles are not known in advance a different approach would be needed.

The vehicle will need to meet certain demands and requirements and these can be used to calculate the amount of energy storage needed. Usually the boundaries for the vehicle's performance are well defined in traffic regulations, thus these requirements can be accurately defined.

5.9.3. MODULAR APPROACH TO DESIGN

In a modular approach the super capacitor, the battery, and the Genset unit would be of the same physical size. In this way the locomotive could easily be adapted to a certain load profile. The load cycle of a switchyard locomotive would most likely require a higher battery power/energy rating and lower rating of the Genset unit. However, if the locomotive is going to perform more as a main line freight locomotive covering longer distances with relatively constant power requirement, this would require more Genset units and fewer batteries and super capacitors. A modular approach would also benefit from the use of more standardized combustion engines such as those in heavy trucks.

5.10 CONDITION MONITORING

A key objective of SUSTRAIL was to increase the availability and cost efficiency of rail freight. A central role is played by condition monitoring to enable timely and relevant maintenance to be undertaken. This Section summarises the train-based condition monitoring work that was undertaken.

A proposition of a monitoring system for the measurement of the temperature and the accelerations of the axle boxes is described. Then, a system to monitor the structural integrity of the axles is introduced. Finally, systems for harvesting power for condition monitoring equipment are described.

5.10.1 ON-BOARD SENSORS FOR FREIGHT WAGON MONITORING

Lead partner:
MERMEC

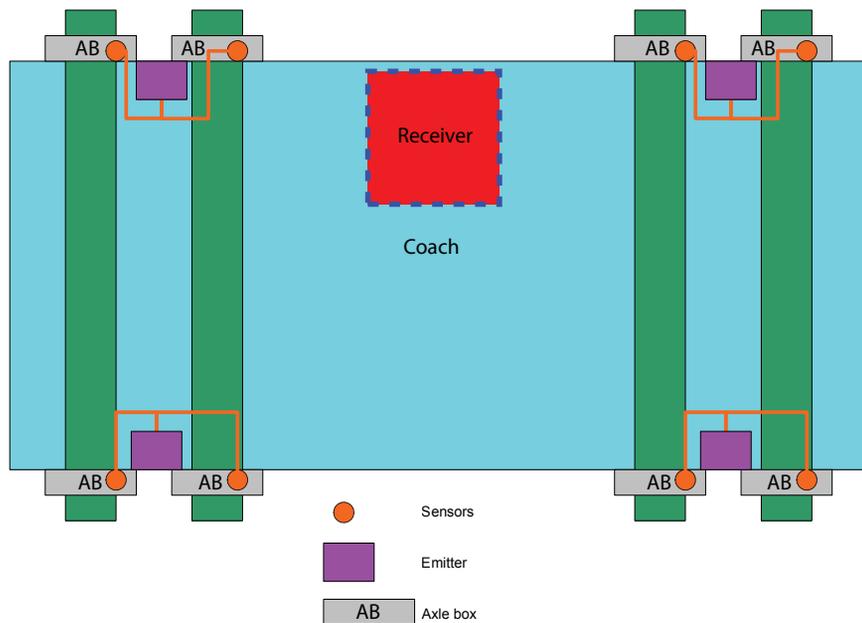
It was proposed that the temperature of the 4 axle boxes plus the acceleration in 3 axes for each side of the bogie be monitored, as shown in Figure 5.25.

In this system each sensor board (emitter) would be equipped with:

- 2 temperature sensors
- an accelerometer
- an emitting module (Wi-Fi)

Each sensor board would transmit all the acquisitions to a coordinator (receiver). The data would be stored on the receiver's database for further processing: detecting abnormally high temperatures; and analysing acceleration evolution over time to detect excessive stresses on the structure. Each sensor board would be battery powered and could be recharged using solar panels, for instance.

Figure 5.25
Measuring system schematic integration



Each emitter would cycle through 3 states:

1. Setup state: the system starts the emitting module and registers to the network in order to send data, then enters “acquisition state”.
2. Acquisition state: this consists of a 1 second loop where an acquisition of the values of the two temperature sensors and the accelerations in the 3 axes is made; these are then sent to the coordinator. The system stays in this state until no more movement is detected by the accelerometer; when this occurs the system enters “sleep state”.

3. Sleep state: the system saves battery life by disconnecting most of its functionalities. The system wakes up when movement is detected through the accelerometer and enters “setup state”.

It is proposed that each sensor board be housed in a metallic box fixed on the bogie. The box would have 4 connectors for:

- The antenna for data transmission
- The two temperature sensors
- Battery recharge / maintenance

This on-board monitoring system and the wireless communication system are implemented on the SUSTRAIL prototype vehicle.

5.10.2 AXLE MONITORING

More details in deliverable D3.5

The feasibility of two different systems for monitoring the integrity of railway axles for freight vehicles has been investigated.

Lead partner: POLIMI

The first monitoring method, “Low Frequency Vibration” (LFV) is based on measuring the bending vibration of the axle and identifying some typical patterns in the waveform and spectrum of these signals to detect the presence of a crack propagating in the axle. The second method, “Acoustic Emission” (AE) is based on detecting low intensity elastic waves generated in the axle by the propagation of the crack.

5.10.2.1 RESULTS

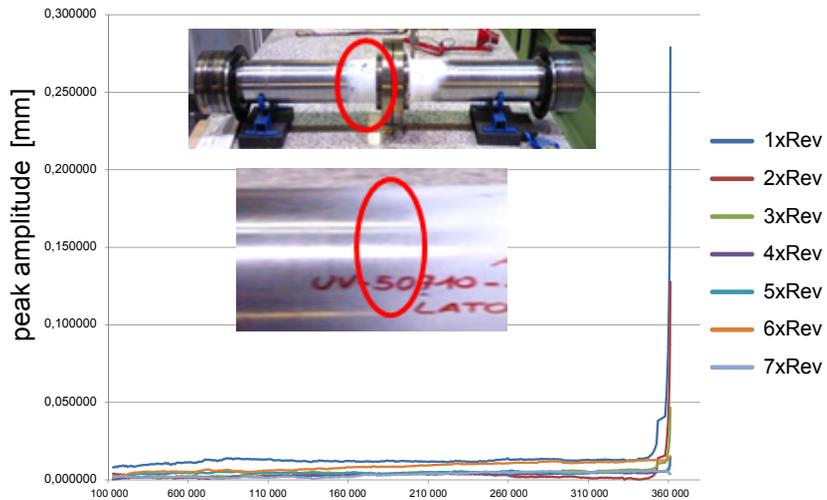
The chosen techniques were judged based on laboratory measurements performed during a crack propagation full-scale test carried out on solid freight axles made of A4T steel; see Figure 5.26.



Figure 5.26
Experimental set-up for full-scale AE and LFV measurements

LFV monitoring: Figure 5.27 shows the trend of the amplitude of the first seven harmonics (1xRev to 7xRev) with the number of axle rotations (loading cycles) for one experiment ending with axle failure (critical crack size reached). It can be seen that the amplitudes are increasing during the test, and hence with the size of the crack. To produce this plot, the raw vibration signals recorded on the laboratory test stand were pre-processed to remove axle shape imperfections, so only showing the increase in the harmonic contents of the signal produced by the crack development process. A photo showing the detail of the crack at the final stage of the tests is also included in the figure.

Figure 5.27
Comparison of harmonics trends of vibration signal from axles tests



AE acquisition: Results of the AE acquisition are shown in Figure 5.28. A clear correlation between the amplitude of AE events and the load applied on the axle under test is observed. The cumulate AE activity indicates that during the load cycles with low levels of load applied the AE activity is low and almost constant, whereas during the higher load cycles it increases significantly.

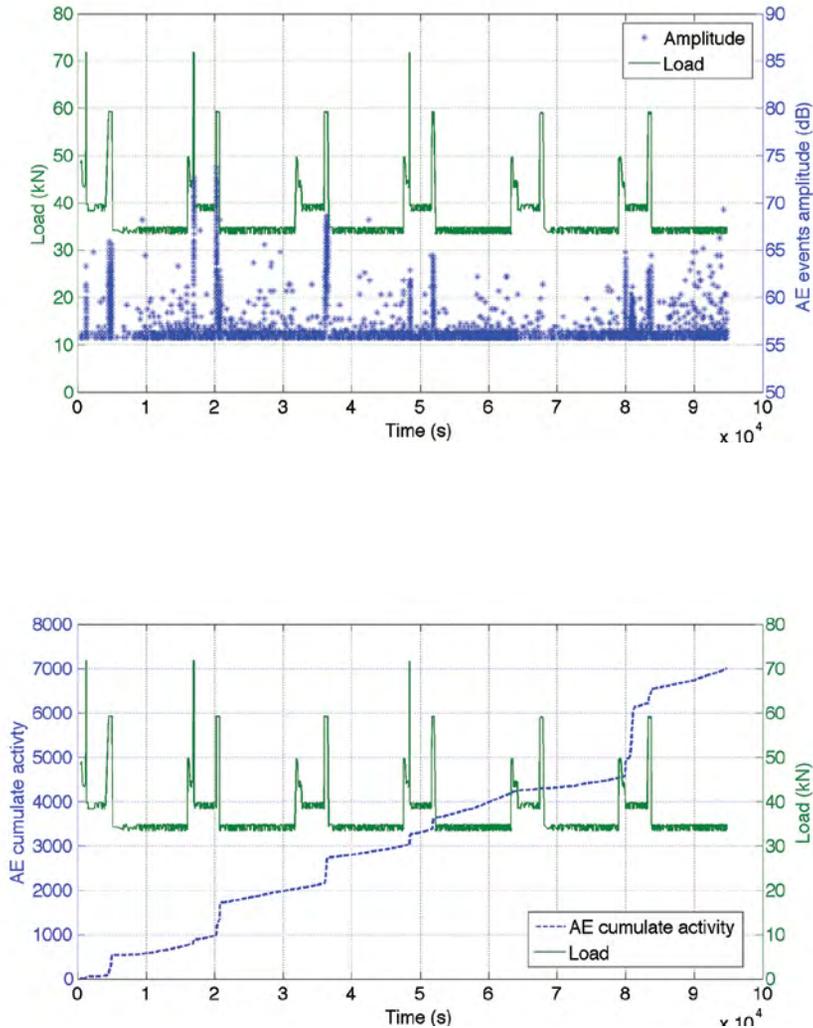


Figure 5.28
Results of the AE acquisition

5.10.2.2 CONCLUSIONS ON AXLE MONITORING

The feasibility of two structural health monitoring (SHM) methods to detect the presence of propagating cracks in freight railway axles was investigated through the analysis of measurements taken on cracked and non-cracked axles during rotating bending fatigue tests.

As far as the LFV monitoring technique was concerned, measurements of the bending vibration of the specimen axles showed a clear correlation between the development of a crack in the axle up to the critical size and the increase in the level of vibration associated with the first seven harmonic components of the axle bending vibration. In the final stage of tests leading to the formation of a crack having a critical size, the amplitude of these vibrations increased up to ten times and more, compared to the values recorded in previous stages of the test when no crack or a small crack was present.

Regarding the AE technique, the amplitude of AE hits was well correlated with the load applied to the axle, even in the initial stages of the tests. Therefore, this technique shows the potential to identify the propagation of the crack at a much earlier stage of the process than the LFV technique, potentially enabling safer and more efficient SHM strategies. However, AE-based structural health monitoring requires more expensive and less robust monitoring equipment and might be more sensitive to disturbances caused by factors such as electro-magnetic interference or ambient noise. Therefore, the feasibility of using the AE method in a real application for railway freight vehicles needs to be further investigated.

More details in deliverable D3.5

5.10.3 ENERGY HARVESTING

Lead partner: TUB

Six different methods for energy harvesting were analysed and compared to the requirements of the SUSTRAIL project. Note that not all proposed measures are “energy harvesting” according to a strict definition of the term; other methods for generating energy were also considered.

5.10.3.1 PHOTOVOLTAIC

Solar modules are a simple solution for energy harvesting and should always be considered. If a solar cell has an efficiency of about 17.5%, then for an energy consumption of about 1.2 Wh per day (calculated during an automatic brake test), the solar cells would have to have an area of at least 0.01 m². A big problem for this energy supply is the day/night shift and weather without solar radiation. So storage methods or alternative energy sources have to be realized. Furthermore the efficiency of the solar cells can be reduced dramatically by dirt or mud. Another important and critical point is the positioning of the solar cells. A flat wagon covered by a container could be very problematic!

5.10.3.2 BEARING GENERATORS

These generate power from rotation of the bearing. The effect of vehicle speed and the speed-dependence of the bearing generators is a problem. Bearing generators from FAG were analysed. These generators were prototypes and had output powers of 5W, 20 to 30 W or 100 W. For the German research project CargoCBM, studying Condition Based Maintenance of freight vehicles, a 20 to 30 W bearing generator was required which needs a minimum velocity of about 30 to 40 km/h.

5.10.3.4 SPRING-MASS-OSCILLATOR

A spring-mass-oscillator mounted on the bogie generates the most energy when it is excited at its (lowest) resonant frequency. The selection of this frequency is difficult due to the fact that a bogie oscillates with several frequencies, dependent on the impacts from the track, wheelset, and suspension. Vibrations with a high magnitude and low frequency are recommended for a maximum electrical output power.

Another type of spring-mass-oscillator is the piezoelectric generator. At a frequency of 80 Hz and a magnitude of 1 mm (impulse) the element has an electric power of 2 μ W. For a simple sensor this element can be a good solution, but not for the whole system. During automatic brake testing, several tests with modified piezoelectric generators were undertaken. The conclusion was that the bogie does not vibrate enough to generate the required energy.

5.10.3.5 THERMOELECTRIC CONVERTER

It is possible to use the different temperatures of a freight wagon to generate energy (the Seebeck effect). Several such devices are available, but the low efficiency of 12% is a disadvantage of this type of energy harvesting, as is the cost, meaning that it is probably uneconomical for freight applications. Furthermore, the only significant temperature difference on a wagon is between the brake shoe or disk and other parts of the brake-system or the bogie frame which would make implementation problematic. Although the efficiency is low, the data looks very interesting: for example, one system generated an electric power of about 10 W at a voltage of 10 V from a temperature difference of 100 K.

5.10.3.6 COMPRESSED AIR GENERATOR

Another possibility for the energy supply is a compressed air generator. This uses the pressure in the main brake pipe to generate energy. In the railway system this type of energy harvesting is not well known, but there is a 20 W compressed air lamp used in mining. Connecting to the main brake pipe is a problem and this element has a high safety requirement so an implementation that uses it would have to work within strict regulations.

5.10.3.7 TRAIN POWER SUPPLY LINE

The use of a train power supply line could be a very interesting solution for the freight train of the future, although this system seems to be relevant just for block train services. Train power supply lines are energized by the main transformer of the locomotive, normally with 1000 V, 16.7 Hz and up to a current of 1000 A. This supply would not be suited for telematics so there would have to be a system installed on the wagon to convert the electrical power.

5.10.3.8 DISCUSSION

All the listed examples have the disadvantage that they only work and generate energy under specific conditions. The solar module does not work in the dark and the other elements do not operate without a locomotive to provide movement, or air pressure. This means that when the freight wagon is not in use, it has to be decided what the telematics should do. To power a stand-by mode, a secondary battery cell (charging required) would be needed. Other options include using fuel cells or primary (not rechargeable) batteries; in the latter case it is very important that batteries have a low self-discharge and are resistant to low temperatures. These batteries, with a life of up to 3 years, may be the most cost-efficient and environmentally friendly option (depending on their recyclability) for some scenarios. However, it is recommended that the SUSTRAIL bogie uses a bearing generator in combination with a primary battery (to use when the vehicle is stationary) for the energy harvesting. This combination is expected to generate the most energy.

5.10.4 OTHER CONDITION MONITORING STUDIES

More details in deliverable D4.5

5.10.4.1 DATA ANALYSIS OF HEAVY HAUL LOCOMOTIVE WHEEL-SETS' RUNNING SURFACE WEAR

Lead partner: LTU

One set of condition monitoring data that is commonly available for wheels is the depth of material removed during re-profiling. A study of heavy haul locomotive wheel-sets' running surface wear data was carried out for SUSTRAIL, extending work that had been undertaken on the Swedish Iron Ore Line (Malmbanan). Statistical inferences were drawn using Bayesian inference to predict reliability related characteristics and a comparison with classical methods undertaken. The main finding was that wheels in different locations have different life-times and that quantifying the expected lives can assist in planning maintenance.

More details in deliverable D3.5

5.10.4.2 USING THE LOCOMOTIVE TO MONITOR FRICTION FORCES

Lead partner: HUD

Another source of condition monitoring data that could be exploited is the locomotive's motor control system. Preliminary work reviewed for SUSTRAIL indicated that it may be possible to identify the friction coefficient between the wheel and rail using this data.

5.11 CHAPTER SUMMARY

This chapter presented the work carried out in SUSTRAIL Workpackage 3. WP3 aimed to develop ‘The Freight Train of the Future’ and was carried out by 14 partners led by the University of Huddersfield and including Universities and industry partners from around Europe. The main aim of the workpackage was to identify the key areas where recent and imminent developments can lead to improved running behaviour of railway vehicles resulting in reduced system maintenance and operating costs for vehicle and track, reduced environmental impact, and greater sustainability and efficiency. An outline performance specification was set for the vehicle following extensive market research and analysis in other project workpackages.

An initial Technology review was carried out by all partners and focused on potential innovative products being used in other modes or industries but with potential to be applied in the following key areas:

- Running gear
- Traction and braking
- Body and bogie structure
- Condition monitoring

All of the potential products were evaluated according to key performance requirements and two levels of SUSTRAIL vehicle were set out:

- Conventional – for which a physical demonstrator would be built
- Futuristic – which would be analysed and modelled but not built

This chapter has focused on the conventional SUSTRAIL vehicle for which a prototype has been built and is being tested. The SUSTRAIL vehicle is capable of running at up to 140 km/h with reduced track forces compared with conventional freight bogies. The main innovations are:

- Novel running-gear using components based on the widely-used Y25 suspension which means that it can be maintained using established techniques, equipment, and staff
- Disc brakes and an electronic braking system to ensure safe operation at the higher operating speeds
- Wheelsets with impact resistant coatings which will reduce inspection costs
- On-board condition monitoring to allow longer maintenance intervals
- Noise-reduction elements to meet anticipated legislation
- Modern lightweight structural design

The design of the SUSTRAIL freight bogie has been patented and a prototype is being manufactured.

INFRASTRUCTURE INNOVATIONS



6. INFRASTRUCTURE INNOVATIONS

The specific aims of SUSTRAIL Workpackage 4 ‘Sustainable Track’ were to “*deal with the improvements needed to be developed on the track side for 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. This will assist in sustainable achievement of increased speed and capacity for freight traffic, thus contributing towards making rail freight more competitive.*”

6.1 INTRODUCTION

There is a very strong coupling to the vehicle workpackage, ‘The freight train of the future’, since it is essential to undertake a systems approach to analyse the combined track and vehicle loads and associated deterioration. The output from WP4 also informed the decision-making for the Business Case workpackage to select the most promising infrastructure technologies for testing and demonstration. Sustainable Track was made up of five tasks:

- Task 4.1: Performance based design principles for resilient track: determine the factors that influence the resistance of track to the loads imposed, and how this can be improved
- Task 4.2: Supportive ballast and substrate: support conditions vital to maintaining track geometry
- Task 4.3: Optimised track systems and geometry: track geometry measures and intervention levels
- Task 4.4: Switches and Crossings: novel S&C component design building on the outputs from INNOTRACK
- Task 4.5: Track-based monitoring and limits for imposed loads: includes definition of Minimum Action Rules

The five tasks complemented each other to deliver new techniques, analysis and modelling tools to understand the challenges of the existing track and vehicle system and also to predict the impact of the proposed SUSTRAIL wagon developed in WP3. Note that maintenance and renewal costs of a typical railway, track and substructure represent 50 to 60% of the total costs, so track and substructure upgrades can achieve a significant impact on the overall costs of railways.

The following sections provide an overview of some of the work undertaken including Overall Approach, Rail, Switches & Crossings, Substructure and Wayside Condition Monitoring (vehicle and track); full details are available in the Deliverable reports.

6.1.1 APPROACH: FAILURES, THEIR IMPACT AND HOW TO “SOLVE” THEM

More details in deliverable D4.3

Lead partner: TRAIN

To identify incoming and futuristic innovations that could lead to a more resilient track, a structured approach was adopted in SUSTRAIL. Initially, a failure modes and effects analysis (FMEA) of the infrastructure was carried out. The approach can be considered to be a “performance-based” approach: from the identification of failure modes and associated risks, the relevant SUSTRAIL innovations were identified in terms of their capacity to mitigate the severity and/or the occurrence of a failure event, or to increase the ability to detect precursors so avoiding failure. The FMEA provided a baseline for the reliability analysis of the track optimization process. In addition, this approach linked with “risk”, “vulnerability” “resilience” and “robustness” that were key criteria for SUSTRAIL.

The FMEA analysis was the first step in a three-step approach to determining the innovations to be addressed in SUSTRAIL. This step was carried out by the Infrastructure Managers (IMs) involved directly within SUSTRAIL through:

- Definition of major potential failures (see Table 6.1)
- Quantification of costs to restore normal service associated with major potential failures and calculation of a “reference” risk priority index (RCPI) as the product of the individual factors: ‘severity’, ‘occurrence’, ‘detection’, and ‘cost’ (see Table 6.2)
- Identification of potential innovations (see Table 6.3), and quantification of costs associated with their implementation, related to the identified major failures, that:
 - » Minimize severity
 - » Reduce occurrence
 - » Improve detection
- Selection of the most feasible (cost-effective) innovations from an IM perspective
- Calculation of an updated RCPI based on the introduction of the selected innovation
- Assessment of the improvement in RCPI that each innovation, once implemented, can provide to the IM (see Table 6.4)

The second step of the approach involved the industrial partners and the research organisations working in SUSTRAIL. They were asked, for each innovation selected in the first step by the IM, to evaluate their capability to effectively implement the proposed innovation and how this could be done within the constraints of the project.

The third step was related to the implementation of the selected innovations. Two levels of implementations were considered:

- **Conventional track:** the innovation is market oriented and can be converted into a commercial solution soon after the end of the project. The proposed innovations were further elaborated and demonstrated within the project and considered in the business case for their quantification in terms of cost/benefit analysis.
- **Futuristic track:** the innovation represents something that cannot realistically be implemented in the short term and should be considered in a longer time horizon. The innovations were mainly investigated at feasibility study level (including simulations) and a conceptual design was the main outcome of the study.

Track Item	Main Function	Locations	Potential Failure Mode(s)	Potential Cause(s) of Failure	Potential Effect(s) of Failure	FIC
Rail	carries load	plain line	brittle fracture	cold environment, over stressing in CWR	vertical fracture, crack in rail cap, derailment	R1
			RCF	curves, bogie stiffness, track irregularities	high maintenance, rail breaks	R2
Earth-works	supports railway	Embankments	embankment erosion	flooding, water, weather, poor maintenance	collapse or dip in track, derailment	E1
			shrink-swell	seasonal moisture content	poor ride, high maintenance, derailment	E2
		Cutting slopes	embankment slip onto track	vegetation, weather, poor construction originally, poor maintenance	soil/rocks/tree stumps on line, derailment, landslide	E3
Track	guides vehicles	plain line	poor geometry	Component deterioration and general geometry degradation under traffic	premature component failure, poor ride, high maintenance, derailment	T1
Structures	supports railway	tunnels	lining failure, rock-falls	ageing asset, erosion of mortar/brickwork by water/ice, geological faults	line closure, loss of service, derailment	S1
S&C	supports railway	junctions	switch rail wear	passing of vehicles	poor ride, flange climb leading to derailment	SC
Joints	connects rails	along the line	rail joint failure	impact damage, fishplate breaks	derailment, loss of capacity/service	J1
Rail pads	holds rail in place	along the line	worn or missing rail pad	traffic and impacts/ poor maintenance	poor ride, propagation of rail foot failure, derailment	RP

Table 6.1

Failure identification codes (FIC)

FIC	Failure Impact/ Performance				Failure Management	Cost Analysis	Cost Impact on Risk
	Severity (S)	Occurrence (O)	Detection (D)	RPI	Recommended Actions	Cost (C)	RCPI
R1	9	6	3	162	Stress free temperature management, Ultrasonic testing	5	810
R2	9	7	5	315	Visual/ultrasonic/eddy current testing	4	1260
E1	8	6	3	132	Water management, Flood defences, Protective layers	8.5	1122
E2	6	3	8	144	Vegetation management, Water management	4.5	648
E3	9	5	4	180	Vegetation management avoiding coppicing, Soil nailing, Protective layers of geotextiles	8.5	1530
T1	5	5	3	75	Reduce speed on the track	6	450
S1	9	5	4	162	Condition monitoring, sprayed concrete linings	5.5	891
SC	7	5	2	53	Train borne condition monitoring, inspection	5	263
J1	8	4	3	79	Renewal or conversion in-situ to CWR	3.5	276
RP	6	3	6	108	Routine programme of pad replacement, use of as hard a pad as allowable	3	324

Legend:

High Impact – Failures that cause serious losses (out of service) and require high costs to restore normal service
Moderate Impact – Failures that cause moderate losses and involve moderate costs to restore normal service
Medium/Low Impact – Failures that cause from low to medium losses and involve low/medium costs to restore normal service

Table 6.2

Failure identification and RCPI (the higher the RCPI, the higher the impact on the infrastructure) from IM perspective, see Table 6.1 for FIC

FIC	Innovations that minimize the severity		Innovations that reduce the occurrence		Innovations that improve the detection	
	NR	ADIF	NR	ADIF	NR	ADIF
R1	n/a		Increase rail cross section	Different steels depending on traffic loads. Welding: use only crucible	Ultrasonic monitoring	WID (Wheel Impact Detectors on track)
R2	Rail Grinding	Harder rails	Improved rail material	Thermal treatments for steel, Different alloys for Steel	Eddy current crack detection	Automated (computerized) visual inspections
E1	Resilient earthworks via piling, materials & drainage	Slope stabilization	Improved drainage, retaining structures		Dynamic stiffness monitoring, laser scanning & ground penetrating radar	
E2	Resilient earthworks via piling, materials & drainage		Resilient earthworks via piling, improved materials & drainage	Weed treatment trains/ trees prune	Moisture content monitoring	n/a
E3	Retaining structures		Shallower gradients	Injections / deep foundations	Cutting monitoring e.g. movement sensors	
T1	Improve installation quality + maintenance, fix before unacceptable levels		Specify geo-grids and under-sleeper pads		Geometry monitoring at an appropriate frequency	
S1	Tunnel linings and ice shields		n/a	Use of composite materials	Automated structure monitoring / inspection	
SC	Install lubrication systems	Hardness of materials	Improved rail material	Crossing geometry	Geometry monitoring at an appropriate frequency	
J1	Strengthen joints, fixing plates etc.		Correct problems with dip angles before too great		Monitor dip angles for planned maintenance	
RP	n/a	Selection guides for appropriate components for traffic, loads, and speeds	Improved rail pad life		n/a	

Table 6.3

Identification of potential SUSTRAIL innovations from IM perspective, see Table 6.1 for FIC

FIC	Selected Innovations from IM NR + ADIF	Updated Performance and Cost				RCPI variation	
		Severity (S)	Occurrence (O)	Detection (D)	Cost (C)	RCPI	Reduction (prior vs. after the introduction of the innovation)
R1	Ultrasonic monitoring and wheel impact detection (WID)	9	6	2	4	408	49.6%
R2	Premium rail steel Automated structure monitoring /inspection	9	6	4	3	567	55.0%
E1	Dynamic stiffness monitoring Laser scanning Ground penetrating radar	7	6	3	9	893	20.5%
E2	Moisture content monitoring	6	2	7	5	351	45.8%
E3	Cutting monitoring (e.g. movement sensors)	9	5	3	8	972	36.5%
T1	Specific geo-grids and under-sleeper pads	5	5	3	6	405	10.0%
S1	Automated structure monitoring/inspection	9	5	3	5	675	24.2%
SC	Improved rail material	7	5	2	4	234	10.9%
J1	Monitor dip angles for planned maintenance	8	4	3	4	280	-1.6%
RP	Improved life of pad	6	3	6	3	206	36.3%

Legend for RCPI variation:

High Impact: Extremely great improvement: The innovation should be investigated and implemented
Moderate Impact: Sensible improvement: It is worth considering implementing the innovation
Low Impact: Some of these innovations were assessed as they had been included in the SUSTRAIL description of work

Table 6.4

Selection of potential innovations from IM perspective and their impact on RCPI, see Table 6.1 for FIC

6.2 RAIL

Deliverable 4.1 (Performance Based Design Principles for Resilient Track) utilised performance based design principles and complementary monitoring tools to determine the factors that influence the resistance of track to the different loads imposed on it by trains, and the means by which this resistance could be improved.

Split into sub-tasks, this work considered both the track as part of a system (in conjunction with the other tasks) and its individual component parts e.g. rails, sleepers, and fastenings. These sub-tasks are described in the following Sections.

More details in deliverable D4.1

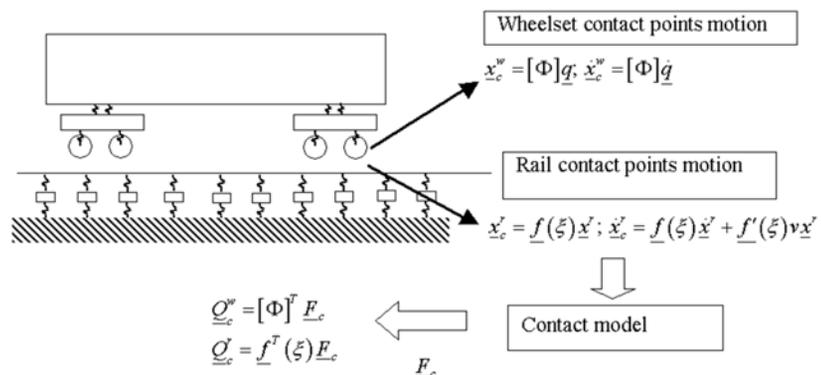
6.2.1 DETERMINE DYNAMIC LOADING OF WAGONS ON TRACK AND KEY COMPONENTS

Lead partner: HUD, POLIMI, KTH

Simulations of vehicle track interactions were undertaken in this sub-task to predict track forces and load distributions. Four UK routes were analysed for distribution of curvature, cant, actual line speed and raised line speed. Track irregularities were also considered to produce a generic track to use in assessments. Analyses using this track allowed static and dynamic forces to be determined for three reference conventional freight wagons and to develop predictions for the reduction in forces due to design improvements for the proposed SUSTRAIL wagons.

Assessment was undertaken of the typical force reaction of the track key components and stresses for the reference freight vehicle (17.5 t, 22.5 t and 25 t axle load) running at 80, 120 and 140 km/h. This also included consideration of fully laden and part laden vehicles, which showed the highest variation in dynamic loading. Thus the proposed SUSTRAIL vehicle needs to have good performance in both load conditions. This work has also highlighted the benefit of reducing un-sprung mass of the wagon to mitigate the increased rail loading resulting from increased speed.

Figure 6.1
Methodologies for train track interaction analysis



6.2.2. INFLUENCE OF TRACK STIFFNESS ON THE DYNAMIC LOADS CAUSED BY WAGONS ON TRACK AND KEY COMPONENTS

More details in deliverable D4.1

Lead partners: HUD, POLIMI, KTH

The scope of this work was to analyse the influence of support condition variability on the vehicle track dynamic interaction. The approach taken was to use a vehicle-track coupling model in which the sleeper ballast stiffness interface can be modified on every individual sleeper to reflect ballast stiffness values.

Data from four UK sites obtained by a “Falling Weight Deflectometer” were used to provide input to the simulations. The simulation results revealed a distribution of ballast force of about $\pm 30\%$ compared to homogenous support; clearly this could lead to differential settlement of the ballast layer. A statistical assessment of the forces on the sleepers was undertaken showing that the local stiffness was generally not well correlated to the ballast force. The variation of sleeper displacements and accelerations with vehicle speed were also analysed revealing that the means increased with speed as did the standard deviation of the accelerations.

The results for a stiff ballast / sleeper interface track were compared with the results for a typical track, see Table 6.5. The comparison was undertaken at the maximum speed considered for each axle load value. The increase of track stiffness led to a significant increase of the rail seat loads and sleeper-ballast contact pressure, in the order of 16 to 20%. This is due to the fact that stiffer track is less efficient than a more deformable one in distributing the wheel load, therefore, the amount of load applied on the sleeper by the presence of a wheel increases for increasing track stiffness. However, a stiffer sleeper support leads to a lower bending moment in the rails, due to there being less deflection. This is the reason why the bending stresses in the rail are lower for the stiff track case, especially for the 22.5 t and 25 t axle loads.

	Track	17 t/axle V=140 km/h	22.5 t/axle V=120 km/h	25 t/axle V=120 km/h
Rail seat load (kN)	Typical	42.8	52.8	56.9
	Stiff	51.0	61.6	67.9
Sleeper-ballast contact pressure (kPa)	Typical	115.0	140.8	153.0
	Stiff	136.6	163.0	179.1
Rail stress (MPa)	Typical	98.8	90.5	113.5
	Stiff	96.7	86.4	93.9

Table 6.5
Comparison of maximum rail seat loads, sleeper-ballast contact pressure and rail stresses for “typical” and “stiff” track

The analysis showed that changes in the track stiffness may lead to significant differences in the mechanical behaviour of the track. A softer sleeper support is beneficial to reduce sleeper loading and to achieve a better distribution of train loads on the ballast and on the lower layers of the track substructure. A decrease of the sleeper support stiffness results in higher bending stresses in the rail, and therefore the use of very flexible sleeper support should be carefully checked against this potential problem.

More details in deliverable D4.1

Lead partner: TATA

6.2.3 DEVELOP A “MINIMUM ACTION RULES” APPROACH TO CORRODED RAIL

Due to its importance in track maintenance, rail foot corrosion was chosen as a suitable defect for the application of Minimum Action Rules. Corrosion defects can have a large bearing on the life of a rail, for example fatigue cracks can be initiated by pitting on the rail foot as seen in Figure 6.2. The Minimum Action methodology was applied to different rail types and corrosion levels. This demonstrated that the technique could be used to assist in planning inspection routines and defining the remedial action required following the detection of a defect.

Three corrosion levels were modelled and results reported using un-randomised single model run data to provide exact figures. The work highlighted that corrosion of even 0.5 mm all around the foot has a significant influence on the lifetime before failure and higher levels of corrosion show even more severe reductions. The 60E2 rail profile shows more resistance to corrosion over 56E1 profile due to the increased cross sectional area.

Figure 6.2

Example of a fatigue crack in the foot of a rail



6.2.4 MECHANICAL TESTING OF TRACK COMPONENTS

More details in deliverable D4.1

The performance of insulated rail joints (IBJ, see Figure 6.3) was identified in SUSTRAIL deliverable 2.5 as needing improvement. A range of tests were undertaken to investigate the effect of varying properties on the performance of rail joints. Some novel tests were undertaken and have the potential to be used to investigate the behaviour of different materials and geometries for insulated joints.

Lead partner: USFD

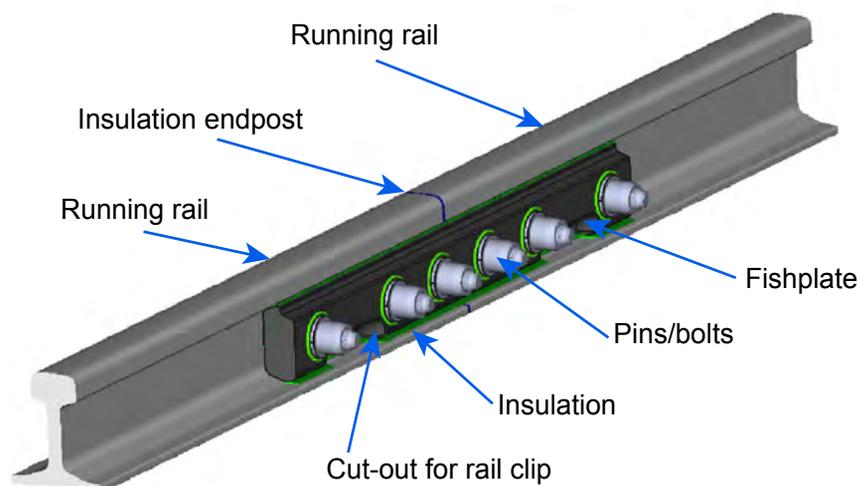
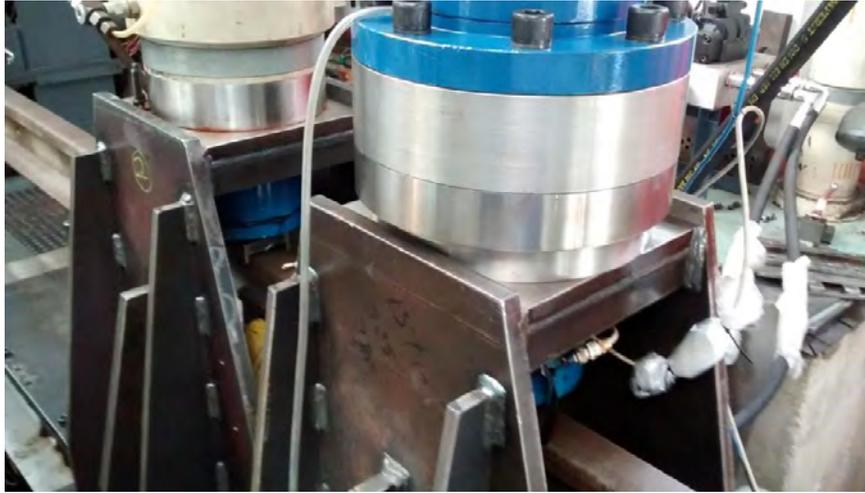


Figure 6.3
Typical insulated joint

The physical testing was supported by finite element modelling, the results of which suggest that the mechanical strength of joints is not adversely affected by de-bonding of glue in the joint, but there may be adverse electrical effects if de-bonding reduces the resistance of the insulation.

It was found that the use of absorbent liners increases the shear capacity of the glued joint. It was also found that hard endpost materials are less prone to failure by lipping, and that the rate of lipping is not affected by the thickness of the endpost. A significant finding is that it is important to check the underside of rails adjacent to joints as high stresses here can lead to failure of the rail. A redesign of the ends of fishplates could reduce the stress concentration at these locations.

Figure 6.4
Mechanical Testing of
Rail Components



6.2.5 RISK ANALYSIS IN THE DESIGN AND OPERATION PHASE

More details in deliverables: D4.1, D5.1

Lead partners: LTU, NR

This sub-task described a risk matrix tool that provides a visual presentation and categorisation of systems and components into different risk groups, see Figure 6.6. Component failure frequencies and the consequences of failure are plotted on a matrix. Further analysis can be done on the items and subsystems to rank them for improvement purposes. In cases for which economic and safety consequences are to be assessed (besides operational consequences), the second axis in the matrix can be changed to a combine all terms. The benefits for Infrastructure Managers of being able to visualise the performance of systems and components are clear.

It is common at the design stage to have limited data for analysis, but techniques such as similarity analysis (for existing system or change in design parameters), stress analysis (for new operating conditions), simulation modelling or expert judgment (for new design) can be used to estimate failure frequency and consequences.

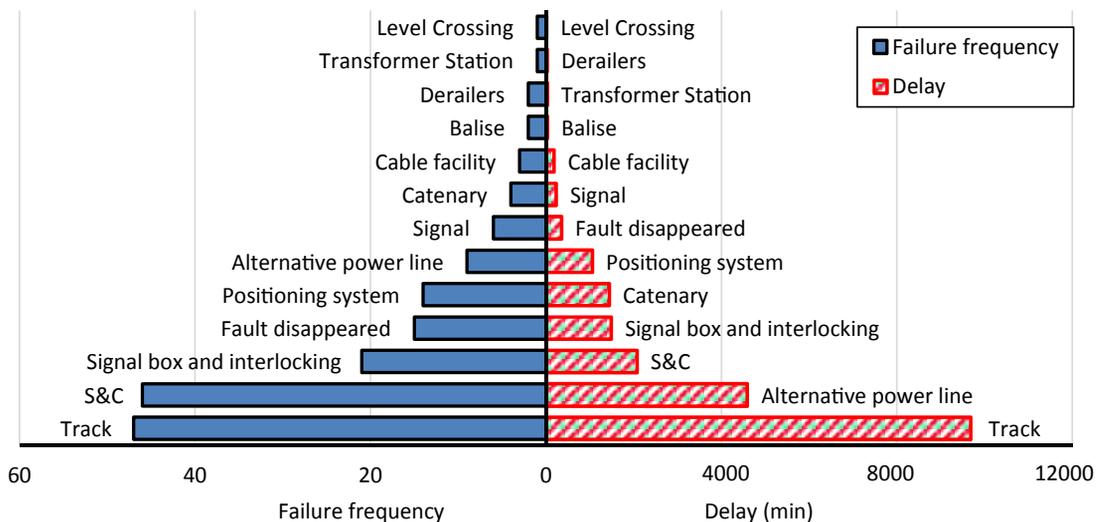
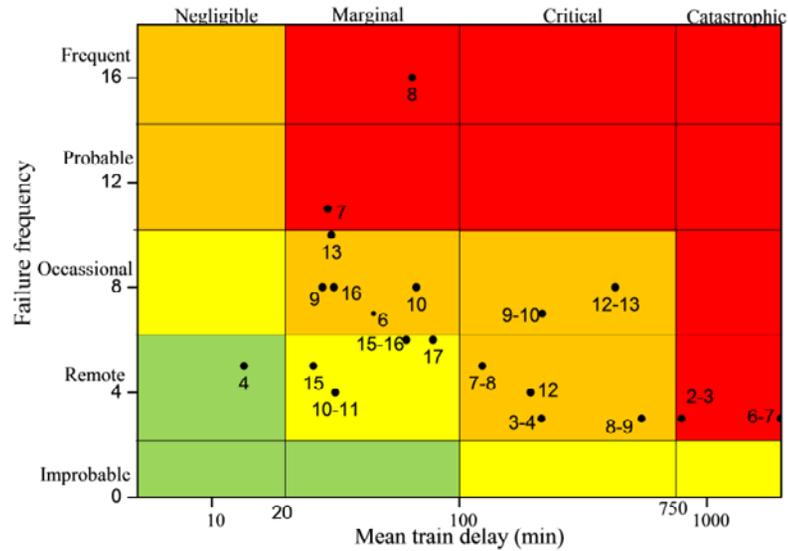


Figure 6.5

Critical failure modes based on failure frequency and delay consequence

Figure 6.6
Categorisation of zones (1 to 37) based on the risk of target performance requirements



More details in deliverable D4.3

6.2.6 MODELLING THE ACCUMULATION OF RAIL DAMAGE FOR MAINTENANCE PLANNING

Lead partner: USFD

In this subtask the growth of fatigue cracks in railheads was modelled. The amount of damage was represented by the depth of material that would need to be removed from the head of the rail to restore an as-new (smooth and un-cracked) profile. A methodology was developed that included:

- a sophisticated crack growth model
- constant rail wear for each wheel pass, but different for each vehicle
- a grinding model that accounted for the reduction in crack growth rate attributed to the change in rail profile

The model was demonstrated on a mixed freight and passenger railway line carrying electric multiple units (EMU) and electric locomotives hauling freight container wagons with a range of loadings based on part of the UK SUSTRAIL route. The rail was assumed to contain a distribution of cracks with depths having a Weibull distribution with a shape parameter of 3 and a scale parameter of 0.3 mm. The results for a standard UK grinding pattern of annual grinding (about 2 million wheel passes) with 0.4 mm of material being removed are shown in Figure 6.7. It is clear that, for this regime, there is an equilibrium crack depth of about 0.5 mm; cracks smaller than this are removed while longer cracks are predicted to continue to grow.

The probability that a crack will continue to grow is thus the probability that a crack of this size or larger will be in the rail; for our assumed depth distribution this is about 1%.

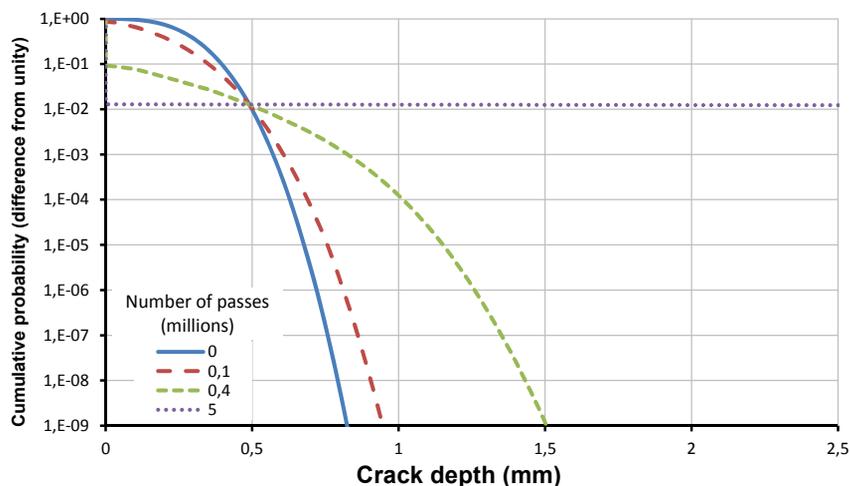


Figure 6.7
Crack depth distribution after various numbers of wheel passages for standard grinding regime

6.2.7 FROM SAFETY LIMITS TO MAINTENANCE LIMITS

Moving from reactive maintenance, based upon safety limits, to predictive maintenance limits has been considered using decision support tools and maintenance strategies to determine the most cost effective points to undertake maintenance activities. This work has included track geometry, contractor performance and tamping and has identified cost effective intervention limits.

The degradation of track geometry is a complex phenomenon occurring under the influence of dynamic loads. Some factors which can affect the track geometry degradation are shown in the Ishikawa diagram in Figure 6.8. These factors are classified as aspects of track design, construction, operation, or maintenance.

More details in deliverable D4.1

Lead partner: LTU

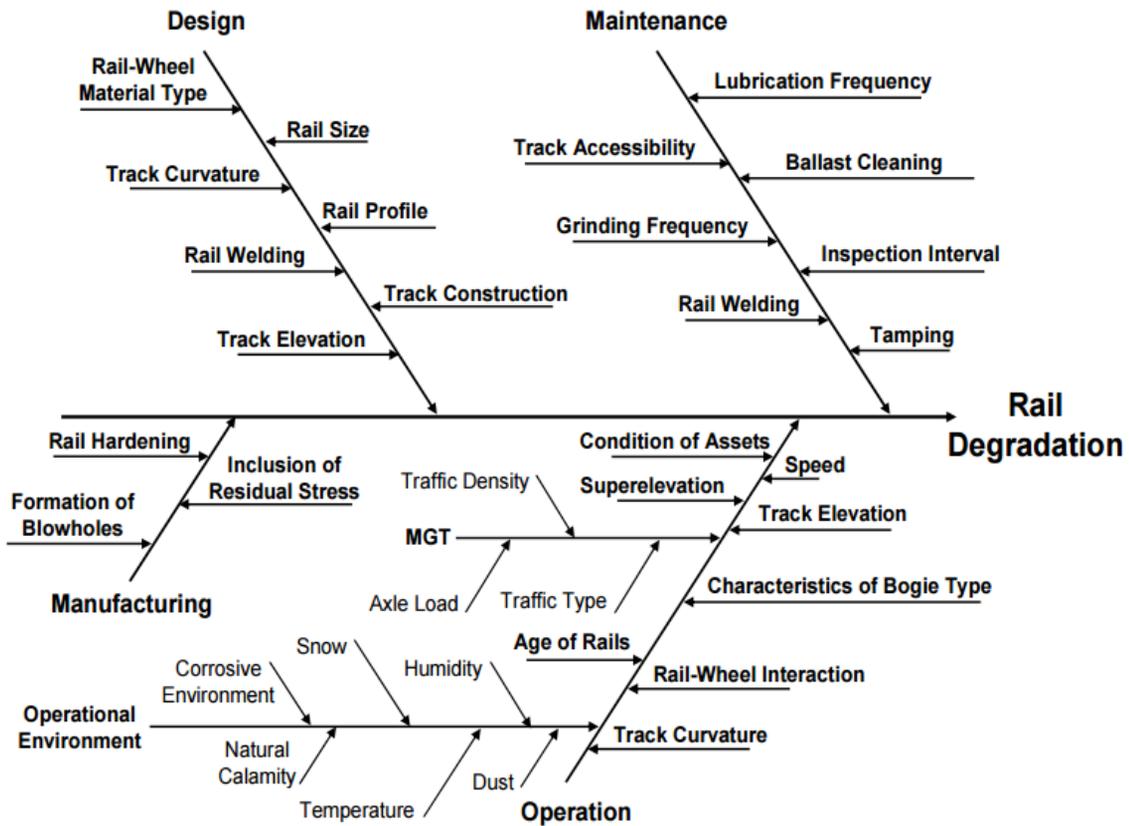


Figure 6.8
Ishikawa diagram (cause and effect diagram) of the factors influencing track geometry degradation

A cost model was developed to specify the cost-effective intervention limits (IL) for track geometry maintenance. The proposed model considered the degradation rates of different track sections and took into account the costs associated with inspection, tamping, delay time penalties, and risk of accidents due to poor track quality. Track geometry data from the iron ore line (Malmbanan) in northern Sweden, used by both passenger and freight trains, was collected to estimate the geometrical degradation rate of each section.

Figure 6.9 is a plot of the standard deviation of the longitudinal level of each track segment measured before and after tamping. It thus shows the effectiveness of the tamping on the selected track sections, between 2007 and 2012. It also indicates the maintenance actions performed at different intervention limits.

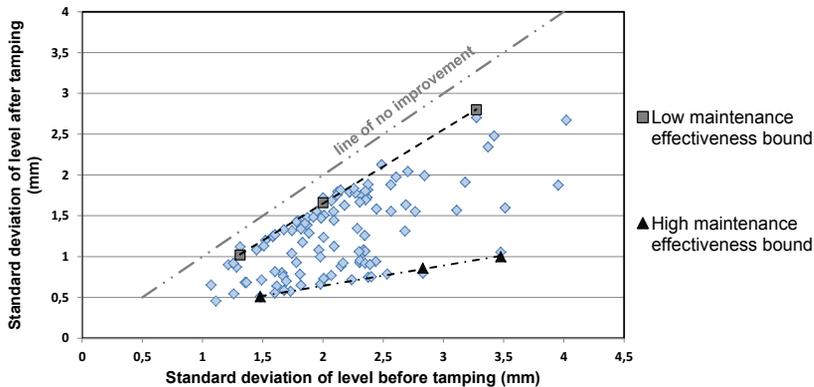


Figure 6.9
Observed tamping effectiveness within studied time interval

The period from April 2013 to October 2017 was simulated. The total maintenance cost per MGT for each IL is shown in Figure 6.10. Depending on the maintenance effectiveness, the actual maintenance cost for each scenario can vary between the high and low maintenance effectiveness boundaries (grey dashed area in Figure 6.10). As can be seen, an intervention limit of 2 mm is the most cost-effective alternative, but this is close to the sharp increase in ‘maintenance’ cost at 2.1 mm caused by the cost of the speed reduction of passenger trains within the one-month planning horizon.

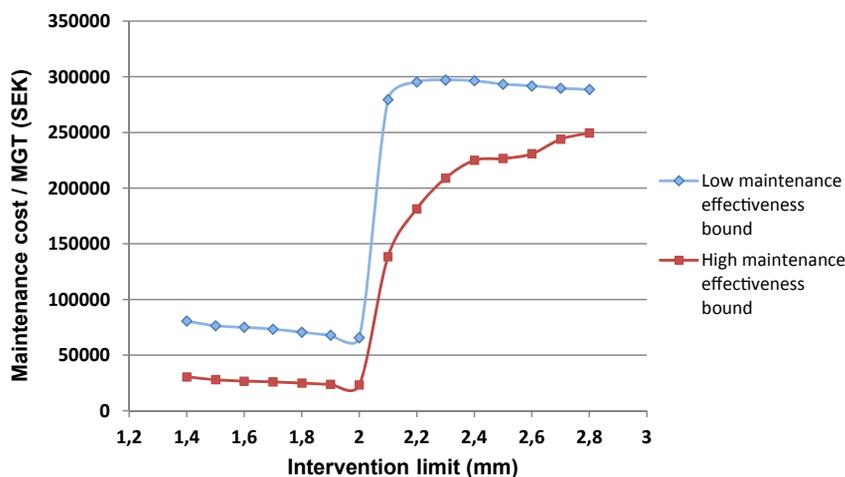
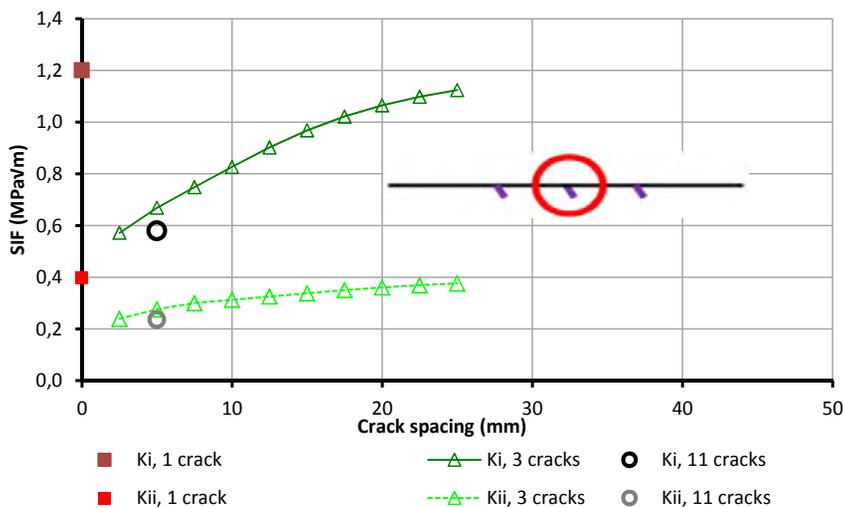


Figure 6.10
Comparison of maintenance cost per MGT for different intervention limits

6.2.8 ROLLING CONTACT FATIGUE: MULTIPLE CRACKS

Rolling contact fatigue (RCF) cracks are an ongoing issue for infrastructure managers who have implemented expensive grinding regimes to control them; better understanding their development would reduce this cost. Most models of RCF crack growth consider only single cracks; whereas RCF damage normally consists of large numbers of cracks. For SUSTRAIL, work on multiple cracks was undertaken. Typical results are shown in Figure 6.11, where it can be seen that a crack in the middle of a group would be expected to grow at about half the rate (half the stress intensity factor, SIF) of a single crack.

Figure 6.11
 Stress intensity factors
 for cracks in middle of
 group



6.3 SWITCHES AND CROSSINGS

Task 4.4 of SUSTRAIL focused on optimising the operation, safety and the reliability of switches and crossings (S&C). The work began with a technology review, followed by data analysis, model development, simulation and physical testing. The areas considered were:

- Point operating equipment (POE), drive and lock mechanisms
- The use of advanced rail materials
- Testing of lubricants for slide chairs
- The geometrical interface between wheel and crossing
- Optimisation of the support stiffness in the area of the crossing panel

6.3.1 BACKGROUND

More details in deliverable D4.4

A typical S&C layout is shown in Figure 6.12.

Lead partner: HUD

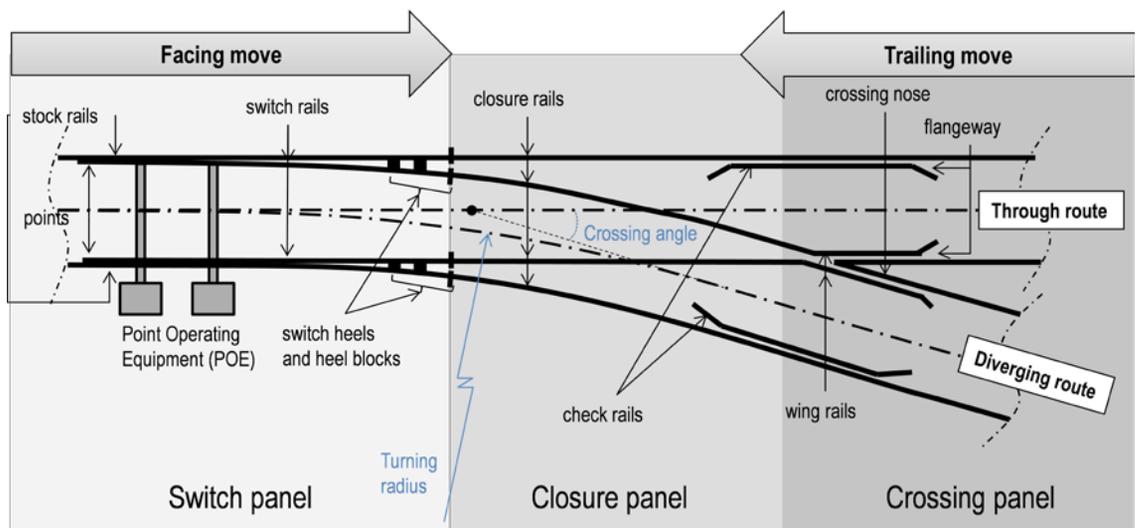


Figure 6.12
Typical switch and crossing (S&C) layout

S&C assets are one of the most costly items in terms of initial installation, maintenance, and renewal. They are also the most prone to failures due to:

- the action of high and repeated loadings (the highest expected dynamics loads of the railway vehicle-track system, those occurring because of the wheel load transferring from switch rail to stock rail and from wing rail to crossing nose (and vice-versa), occur at S&C)
- their intrinsically weaker structure (thin, unsupported switch rails)
- the need to have moving parts in exposed locations (corrosion, contamination, obstruction, seizure)
- powered machinery (machine faults, theft)

In order for the project to target significant S&C failure mechanisms, the main failure modes were reviewed (Table 6.6) based on consortium experience and literature searches and the most relevant root causes were highlighted. This underlined the strong relevance of the modelling work taking place to understand issues surrounding the dynamic interaction between vehicle and track, either due to poor compliance between wheel and rail geometry (section 6.3.5) or poor support conditions (section 6.3.6). All rails in S&C are affected by these two conditions while at the same time the use of advanced premium steels (section 6.3.3) can help significantly reduce damage such as wear, plastic deformation, spalling, and shelling. Poor operation of POE can be improved by looking at the material and lubricants used at slide plates (section 6.3.4), and finally the use of advanced POE equipment (section 6.3.2) can contribute to lowering the impact of failures of these elements.

Panel	Component	Failures	Causes
Crossing	Cast manganese Casting	transverse fatigue crack (foot or nose)	poor support, high dynamic forces, design flaw
	Crossing nose	wear, plastic deformation, shelling and spalling	high stress intensity wheel rail contact conditions, poor compliance of wheel and rail geometry and high dynamic interaction
	Wing rail	wear, plastic deformation, shelling and spalling	high stress intensity wheel rail contact conditions, poor compliance of wheel and rail geometry and high dynamic interaction
	bearers	fatigue cracking, voids	poor support condition and maintenance, high track dynamic interaction
Switches	switch rails	lippings, head checks, squats, wear	high stress intensity wheel rail contact conditions, poor compliance of wheel and rail geometry and high dynamic interaction
	points	all the above + fracture by fatigue	as above + poor connection to stock rail or obstruction
	stock rails	lippings, head checks, squats, wear, spalling	high stress intensity wheel rail contact conditions, poor compliance of wheel and rail geometry and high dynamic interaction
	slide plates	poor movement (high friction) and seizure	poor support maintenance (differential settlement and alignment), poor lubrication, contamination
	bearers	fatigue cracking, voids	poor support condition and maintenance, high track dynamic interaction
Point Operating Equipment	motor, drive & lock mechanisms	motor/mechanism operation failure, loosening of element and loss of accuracy ...	obstruction, water ingress, poor maintenance, interaction between track vibration and POE fixings
	back-drive mechanism	loose elements and poor adjustment	obstruction, poor maintenance, interaction between track vibration and POE fixings
	stretcher bars	loose, cracked or broken fixings	poor maintenance and high dynamic vibration (vehicle-track interaction and track-component interaction)
	control, electronic, hydraulics & detection	failed sensors/relay, loose/damaged/leaking hydraulics	environmental damage (water/ice, wind...), high dynamic vibration, poor installation and maintenance

Table 6.6
Typical failures in S&C and their expected root causes

6.3.2 POINT OPERATING EQUIPMENT (DRIVE AND LOCKING DEVICES)

6.3.2.1 ASSESSMENT OF DRIVE AND LOCKING MECHANISM FAILURES

Failure data analysis based on the UK selected freight corridor of interest (Southampton and Felixstowe to the North West of England) over the year 2012-13 revealed that 13% of the recorded failures had no identifiable cause and the second highest proportion, 10%, was entered as 'null'. Significant disruptions resulted as the requirement for maintenance personnel to attend and inspect means a route is temporarily unavailable. The majority of the remainder of failures were related to connections in the mechanical linkages between the switch rails and the rest of the drive and locking mechanisms, e.g. back-drive mechanism, supplementary detection, locking mechanism, detection rods, stretcher bar failures, rail position sensor (LVDT), and detection assembly, which each accounted for between 8% and 2.3% of the failures. The data above therefore shows that reducing the number of false or null failure indications and improving the diagnosis of failures (by improving the condition monitoring) would significantly reduce disruptions.

6.3.2.2 EQUIPMENT DESIGN

A thorough review of the INNOTRACK recommendations was made in the context of the SUSTRAIL freight corridors and supported by a failure analysis specific to the SUSTRAIL UK routes. It was concluded that the design specifications for the physical arrangement, modular design, standardised components and interface protocols developed by INNOTRACK should be adopted along with condition monitoring of the drive, locking, and detection device, and relevant parameters of the S&C unit. It is anticipated that the adoption of these design specifications with condition monitoring would increase the maintainability of the S&C unit and component life, improve reliability through fault detection and prediction, and enable the adoption of efficient condition based preventative maintenance strategies.

6.3.3 ADVANCED MATERIALS

More details in deliverable D4.4

6.3.3.1 SUMMARY

Lead partner: TATA

A range of high performance rail steel products by Tata Steel have already been proven to increase performance in plain line to combat wear and RCF. Some testing has also taken place in switch blades to avoid issues with head check, plastic flow and flaking as well as wear. In the area of advanced materials the main output from SUSTRAIL is strong evidence of the benefit offered by premium grades of steel to combat the degradation observed on switch blades over their lifetime. R350HT has demonstrated a high resistance to wear in comparison to R260 grade rail. HP335 has demonstrated both excellent wear resistance and RCF resistance in a switch blade application. Bainitic grade BLF320 showed excellent RCF resistance in switch blades however the wear resistance is similar to that of a pearlitic rail of similar hardness.

6.3.3.2 INNOVATIVE MATERIAL SELECTION AND TESTING

R350HT is heat treated above the austenite transformation temperature with controlled air cooling. It has shown improvement both in terms of wear and flaking with respected to conventional R260 rail after 18 months installation, see Figure 6.13.



Figure 6.13

Picture of R350HT showing less flaking compared to R260 grade switch blade (right)

HP335 is a pearlite steel which has been improved by increasing the volume of cementite while also increasing the strength of the ferrite. Site observations have shown switch blades to be in place for over 48 months in places where they were normally replaced every 24 months. However current repair methods have proved difficult or ineffective; this is an area requiring further work in order to take full advantage of these premium steels.

Bainitic rail steels with low carbon content (BLF320 & BLF360) have better performance in terms of surface cracking and wear resistance than standard steels, since they are tougher, more ductile and have higher proof stress. Figure 6.14 shows evidence of this from site testing on switch blades. These steels are readily weldable and have no requirement for heat treatment.

Figure 6.14

Photograph from a test site showing (left) R260 switch blade and (right) Bainitic switch blade after a similar level of traffic.



More details in deliverable D4.4

6.3.4 LUBRICANT TESTING ON SLIDE PLATES

Lead partner: USFD

6.3.4.1 SUMMARY OF OUTCOMES

Testing methods of switch rail slide baseplates have been developed to better understand friction element behaviour and to determine those lubricants that best improve performance. The testing focussed on baseplates that are near the heel. These experience high vertical loads due to their proximity to the rail clips and only move a short distance when the points are changed. They are thus prone to seizing. Significant immediate and the long term benefits have been demonstrated from the use of advanced lubricants with respect to dry conditions and conventional options.

6.3.4.2 TESTING CONFIGURATION AND RESULTS

Two testing methods were employed: a small scale (Plint) reciprocating test and a full scale bi-axial test. The first provides a prescribed (sinusoidal) horizontal movement with a fixed vertical force onto a small cylindrical specimen. These tests are rapid and cheap, but further work needs to be done to correlate results to track conditions.

The bi-axial test used a full-size section of switch rail and baseplate in a hydraulic test machine that can produce the varying forces and movements both vertically and horizontally necessary to replicate loading in track, see Figure 6.15. The load cycle is shown in Figure 6.16: lateral movement of the switch rail with vertical clamping load (identified as heel movement), followed by the vehicle loading “VIM” – rapidly varying vertical loads and lateral movement induced by the passage of each of 12 wheels. Note that the two switch-rail specimens are mounted vertically so lateral movement in track is accomplished by vertical movement in the test. Typical results are presented in Figure 6.17 showing those lubricants which are producing increased performance (low coefficient of friction and stable results throughout the test), those producing poor performance (increasing friction coefficient during the test) in comparison with the dry reference condition (black line).

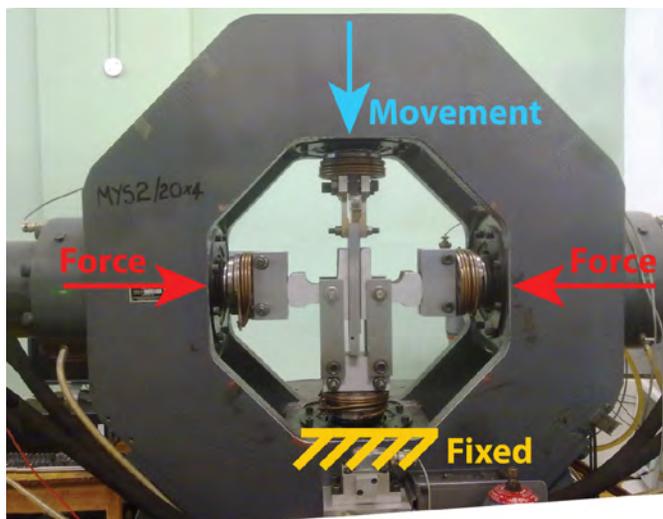


Figure 6.15
Bi-Axial test rig

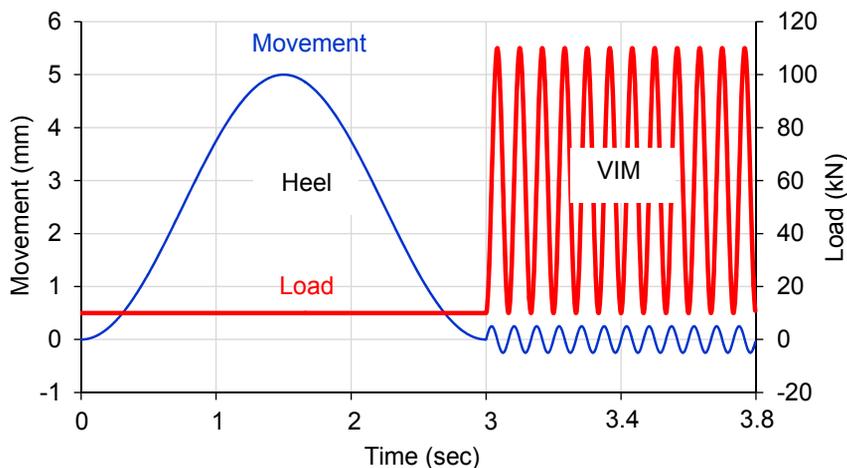
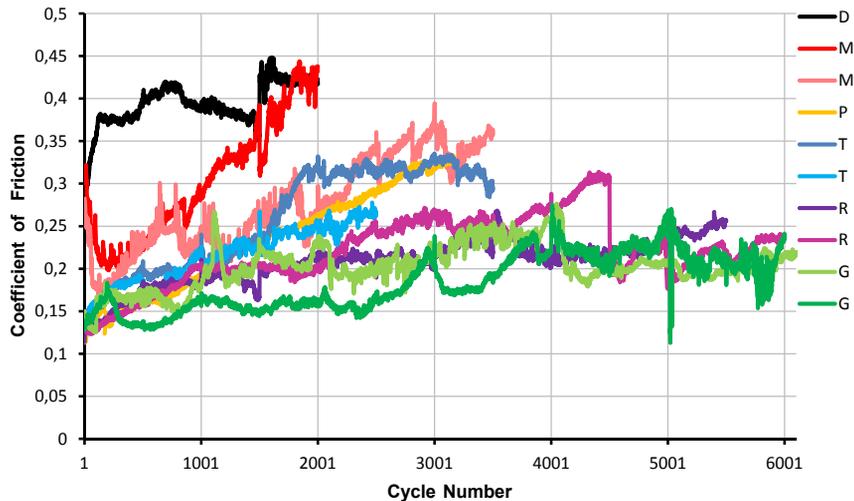


Figure 6.16
Loading environments on slide plates near heel (one load cycle)

Figure 6.17
Biaxial test normal
service results



More details in
deliverable D4.4

6.3.5 GEOMETRICAL INTERFACES

Lead partner: HUD

6.3.5.1 SUMMARY OF OUTCOMES

The main outcome of the project in the area of geometrical interface between wheel and rails has been to further the understanding of the impact of vehicle and wheel shapes on the vertical damage at crossing panels. The tasks produced advance simulation algorithms and techniques capable of handling large set of vehicle and track conditions to help identify those properties in the system leading to disproportionate damage. For example, particular shapes of wheels (e.g. increased conicity) were shown to lead to increased vertical impact forces. Future work will focus on defining limit values as well as proposing automated control techniques. This work will be extended in further European projects such as Capacity4Rail and In2Rail to suggest optimised wheel and rail shapes and improved support solutions.

6.3.5.2 MODELLING THE FORCE IMPACT OF WHEEL PASSAGE AT A CROSSING PANEL

A simulation model based on a multi-body system (ordinary differential equations) was developed to simulate the interaction between vehicle suspension and track at a crossing in the vertical direction, see Figure 6.18. It was calibrated against a custom 2D finite element model that had been enhanced during the project. The calculated vertical force was filtered at different cut-off frequencies to study forces corresponding to different degradation mechanisms, e.g. filtering at 280 Hz provides results corresponding to the ‘P2 force’, a nominal static plus inertial force correlated with rail damage. Influential parameters such as vehicle speed, vehicle primary suspension, and unsprung mass, facing and trailing direction, crossing type, and crossing angle were looked at. More particularly the

study focused on the effect of wheel shape and attitude (i.e. lateral displacement and angle of attack) on the forces in the load-transfer (nose) area of the crossing. The geometrical motion of the axle through the crossing panel was calculated based on the rolling radius map and used as input to the multi-body system (z_{irr} in Figure 6.18).

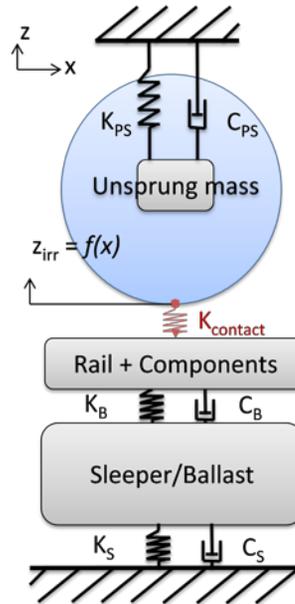


Figure 6.18
3 DOF multibody unsprung mass / track model

Example results in Figure 6.19 show the effect of speed on the low-pass filtered results with the force oscillation (top plot) and the wheel motion through the dip shape of the crossing nose (bottom plot). From these time predictions the peak force can be quantified and further analysed against the input parameters of interest. For example Figure 6.20 shows the force (filtered and unfiltered) and the theoretical ‘P2 force’ (calculated according to the UK specification) increasing with unsprung mass for three different speeds. The unsprung mass above which the ‘P2 force’ reaches the accepted UK limits (“Jenkin’s limit”) is highlighted for each speed.

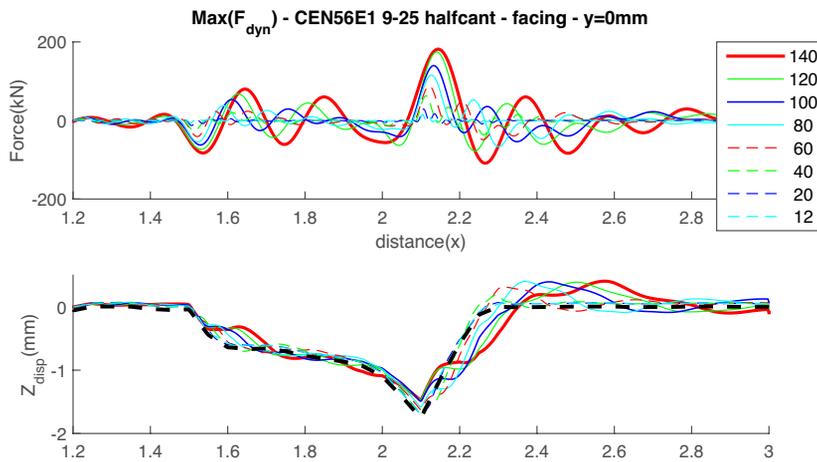
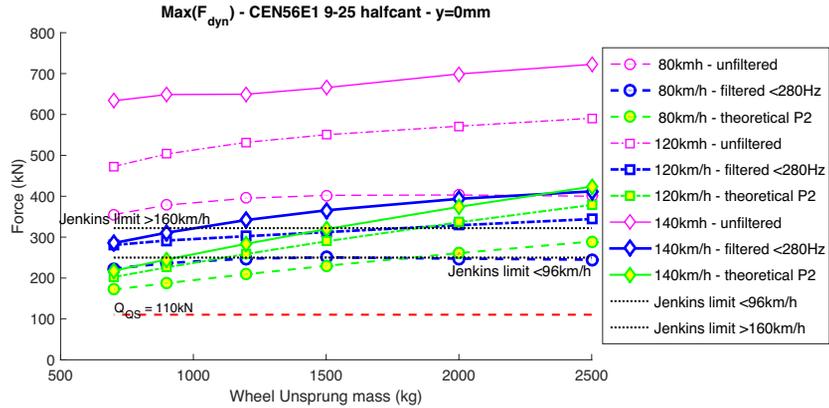


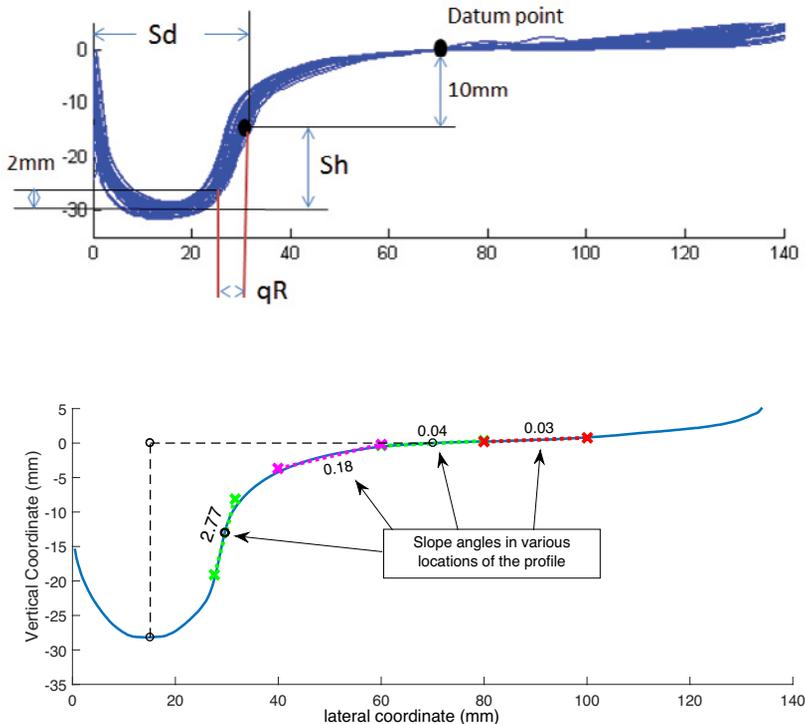
Figure 6.19
Effect of speed on vertical forces at a CEN56 V 91/4 crossing in facing direction

Figure 6.20
Effect of unsprung mass on dynamic force on CEN56E1 1:91/4 (peak force)



Investigations were also carried out on a population of representative worn freight wheel shapes, see Figure 6.21. It was shown that there are wheel shape characteristics that are correlated with the level of force. In Figure 6.22 the ‘hot’ colours indicate higher peak forces, increasing with flange thickness and wheel cone angle. The correlation between the equivalent dip angle experienced by the wheel and the peak force level was clear, and populations of wheel with identifiable characteristics could be isolated as contributing the majority of the high forces. For example, Figure 6.23 shows that wheels with increased conicity (>+50%) due to wear experience the largest dip angle and produce peak forces some of which are over the accepted limit.

Figure 6.21a
Wheel shape x and y-coordinates population with standard statistic measures (top), additional wheel measures for local slopes in different contact zones depending on wheelset lateral motion (bottom)



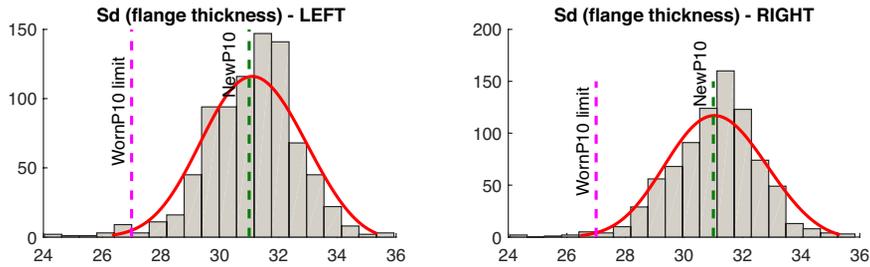


Figure 6.21b
Wheel population statistical flange thickness distributions

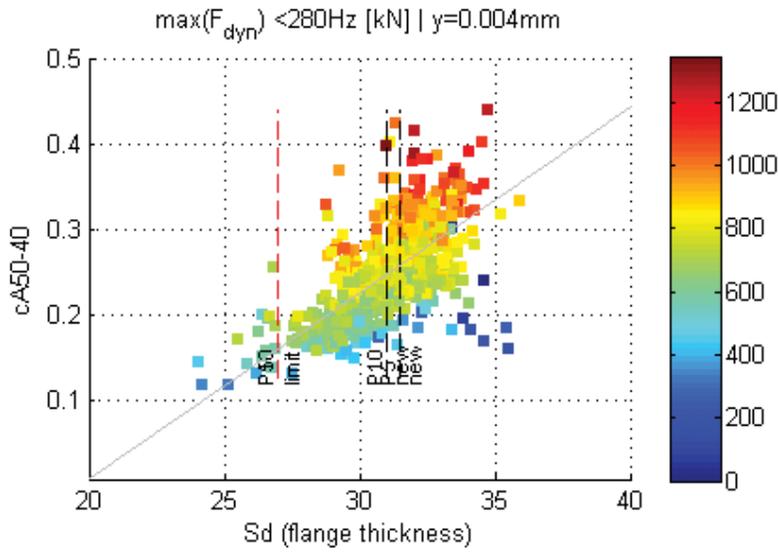


Figure 6.22
Wheel population statistical flange thickness distributions

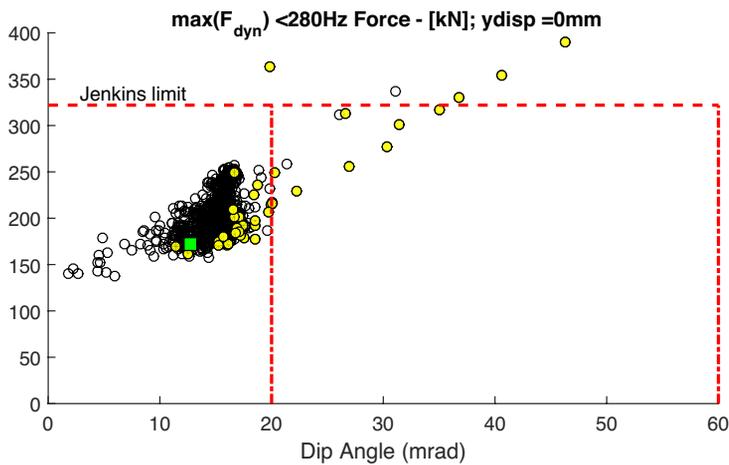


Figure 6.23
Dynamic peak forces (filtered <280 Hz) against equivalent dip angle. Yellow markers indicate wheels with >50% increased conicity at nominal radius. The green square is the P10 reference wheel.

6.3.6 SUPPORT STIFFNESS

Lead partner: NR

6.3.6.1 SUMMARY OF OUTCOMES

The main outcome of the project in the area of support stiffness optimisation has been that vertical damage in the area of the crossing panel can be improved under a wide range of track support condition by the addition of resilient layers. It was shown that the use of under-sleeper pads can be very effective in limiting the vertical forces transmitted to track components and supporting layers. Furthermore they were shown to be very effective at lowering and equalising stresses in the foot of cast crossings and also at significantly reducing differential stresses on supporting ballast layers.

6.3.6.2 SITE INVESTIGATION

Two types of Under-Sleeper Pads (USP) were installed at a Network Rail (UK) site at Wooden Gates on the East Coast Main Line as shown in Figure 6.24. The main issues addressed with USPs are the mitigation of impact loads such as those in the crossing panel, and therefore the reduction of associated degradation such as sleeper voids, uneven ballast settlement, and fatigue of crossing castings. There is already strong evidence that the use of USP helps spread the wheel loads more evenly onto the track structure and supporting layers (illustrated in Figure 6.25) as well as reducing the pressure between the top ballast surface and the sleeper bottom surface (illustrated in Figure 6.26).

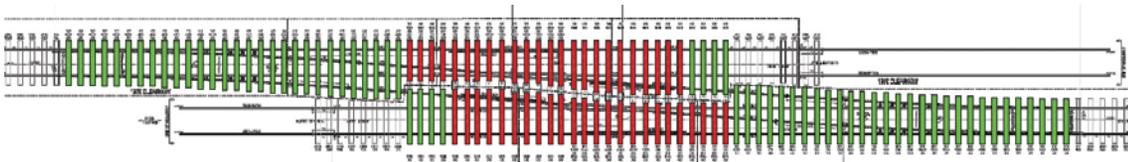


Figure 6.24 Location of USP on 502A/B crossover at Wooden Gates

- Green: Switch panel USP, Stiffness = 0.22 N/mm³ (Harder)
- Red: Crossing panel USP, Stiffness = 0.15 N/mm³ (Softer)

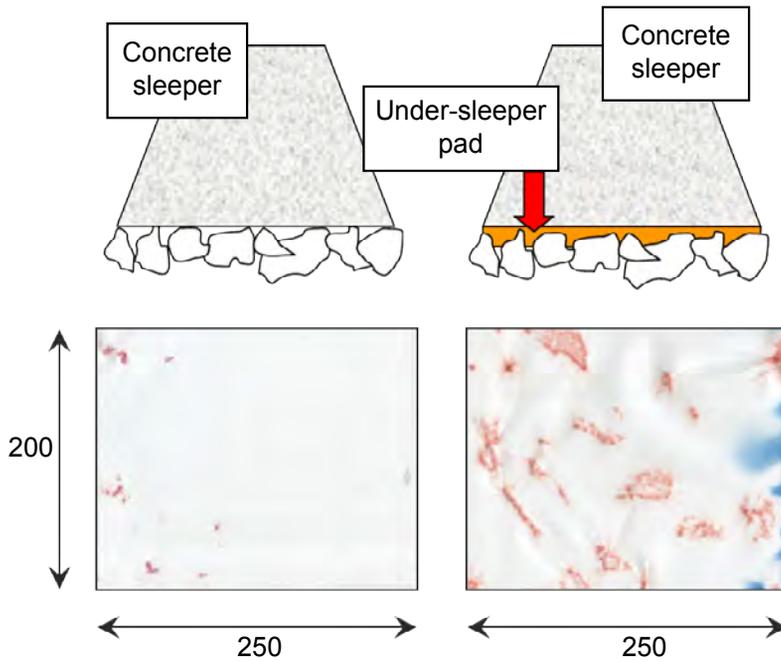


Figure 6.25
Increased contact area
between bearer and
ballast

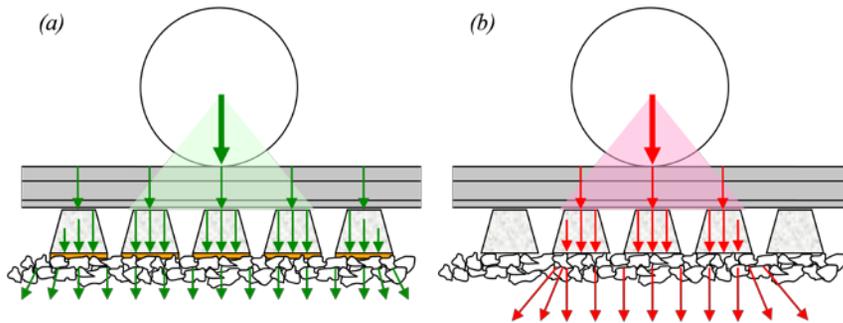


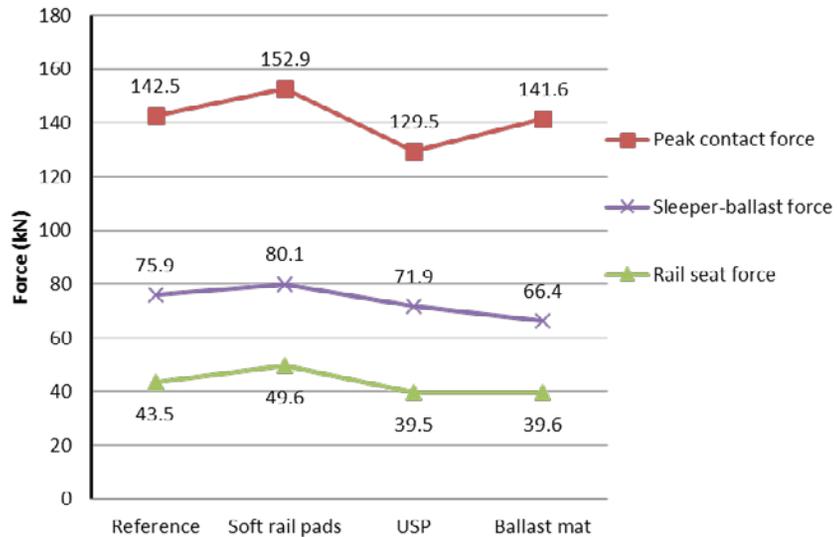
Figure 6.26
Distribution of load
transmitted to track
foundation with USP
(a) and without (b)

The main conclusions from using a “Falling Weight Deflectometer” (to measure stiffness and critical speed at 56 locations through the site) were that USPs reduce the influence of formation stiffness and that they help improve the uniformity of system stiffness, reducing the standard deviation of sleeper deflections. However, the softer pad used at Wooden Gates is considered too soft for typical UK applications as, without a very stiff formation, the increase in deformation of track components will increase. Examining the condition of the ballast it was evident that USPs had had a positive effect on the overall condition of the ballast.

6.3.6.3 NUMERICAL MODELLING

A full 3D finite element model was used to investigate the effect of adding resilience at different layers of the track (e.g. soft rail pads, under-sleeper pads and ballast mats). The main results were that USPs and ballast mats were the most effective means of reducing the ballast layer and rail seats force Figure 6.27. However their properties have to be carefully chosen as they also lead to an increase in rail bending moment of the order of 10 to 15% (with the simulated properties and load cases).

Figure 6.27
Peak force level
in different layers
of track with
various resilient
configurations



The 2D finite element model mentioned in Section 6.3.5 was used to investigate the effect of USPs in the presence of voided bearers. This analysis showed that the force level in the crossing panel when there are voided sleepers increases and the location of the highest load changes. Not only the load-transfer area of the crossing nose is affected but also the leg end zones near the tri-metallic weld, about 21.5 m through the site; fatigue cracks are observed at this location. The addition of USPs in these conditions was also predicted to lower and equalise the force level in the different track layers and to reduce the stresses at the foot of the casting. Note that USPs would help control the presence and the development of voids in the first place.

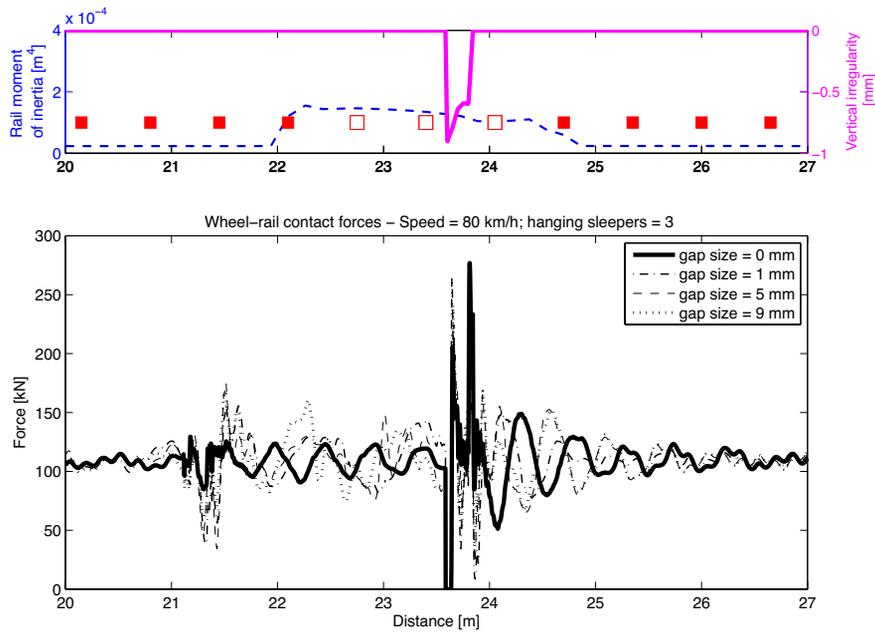


Figure 6.28
 Time history of wheel-rail contact forces in the crossing panel for 3 hanging sleepers and three gap sizes (0, 1, 5 and 9 mm) at 80 km/h. The upper plot shows position of sleepers (\square), dip angle irregularity and rail / cast crossing bending stiffness properties.

6.4 SUBSTRUCTURE

The objective of Workpackage 4.2 was to identify the impacts of substrate stiffness variation on track geometry deterioration and other track defects such as the effect of vertical plane long wavelength rail bending on rolling contact fatigue crack growth. The activities focused on the role of structures such as bridges and embankments, and track substrate stiffness, in enabling the railway to effectively bear the loads to which it is subjected.

More details in deliverable D4.2

Lead partner: NR, ADIF, NRIC

6.4.1 TRACK FOUNDATIONS: DATA AND PRACTICE

The infrastructure managers (IM) provided detailed site data for use in analyses and described current desk-based and on-site investigations used to assess the adequacy of trackbed stiffness. The on-site investigations can be intrusive (digging trial pits) or use a Falling Weight Deflectometer to assess stiffness and critical speed. It was reported that up to about four times the depth of granular trackbed layer (maybe a metre) can be required to produce the same dynamic sleeper support stiffness when running over well-drained soft clay compared to very stiff ground. If good drainage is not available the expected stiffness will approximately be halved.

IM consider that a stiff trackbed results in better track quality needing less maintenance, resulting in lower whole life cost. Whilst a stiff track bed results in higher ballast loading as mentioned in Section 6.2.2, it is clear that this is within acceptable limits and other benefits from reduced ballast movement results in less ballast deterioration and therefore increased durability. Very low trackbed stiffness can result in trains approaching the “critical velocity” when they travel at the same speed as the displacement wave they generate in the substructure. Unless speed restrictions are introduced this results in rapid deterioration of track geometry.

6.4.2 TRACK AND SUBSTRUCTURE MODELLING

More details in
deliverable D4.2

The objective of this part of the study was the development of a numerical approach for the analysis of track substructure and embankments, potentially subjected to large deformations and accelerations induced by a running vehicle.

Lead partner: TRAIN

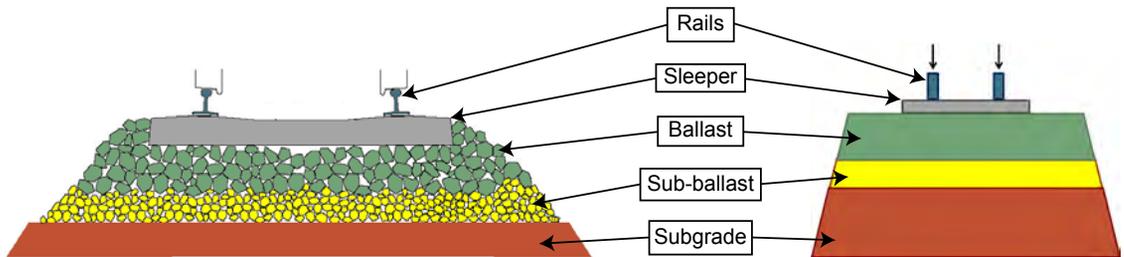


Figure 6.29

Sketch of a transverse section through track geometry (left); Sketch of the geometry of the finite element models of the transverse section (right)

STATIC ANALYSIS OF STRAIGHT RAILWAY TRACK AND SUBSTRUCTURE

A static analysis was first carried out to study the global response of the railway track to the loads imposed by a freight vehicle. The finite element model represented a 36.2 metre section of railway track. Half of the track was modelled with symmetry imposed on the centreline and the bottom part of the subgrade had all degrees of freedom fixed. The train loaded the track with static vertical forces at each axle location. Rails were modelled as cuboids with a rectangular cross-section having equivalent bending and compressive stiffness to a UIC 60 rail section; an isotropic elastic material model for steel was used. Sleepers were modelled as rigid cuboids. Half a sleeper was modelled with a mass of 125 kg. The substructure was modelled using isotropic elastic materials. The main material properties are reported in Table 6.7.

Table 6.7

Train, superstructure,
and substructure
properties

Component	Parameter	Value
Wheel	Mass	750 kg
	Density	7850 kg/m ³
	Young Modulus	210 GPa
Track	Total Length	36.2 m
	Dimensions (H*W)	200*50 mm
Rail	Density	7850 kg/m ³
	Young's Modulus	210 GPa
Concrete Sleeper	Spacing	0.6 m
	Dimensions (L*H*W)	2.5*0.2*0.2 m
Ballast	Dimensions (H*W)	1*3 m
	Density	1600 kg/m ³
	Elastic Modulus	350 MPa
Sub-ballast	Dimensions (H*W)	0.5*3.5 m
	Density	1900 kg/m ³
	Elastic Modulus	100 MPa
Subgrade	Dimensions (H*W)	2*4 m
	Density	2000 kg/m ³
	Elastic Modulus (soft)	10 MPa
	Elastic Modulus (stiff)	80 MPa

Figure 6.30 shows the magnitudes of total displacements calculated for a tare (5 t axle-load) vehicle. It can be seen that, in the case of a soft soil, the effect of the loading is recognisable well inside the structure, with a transmission of the load from the ballast to the sub-ballast to the subgrade. The higher deformations are localised in the ballast and sub-ballast. So, in the case of soft soil, the structure is less stable and is at risk of failure of the shoulder of the embankment. In the case of stiff soil the embankment shows a greater stability with transmission of the load more in-depth within the body of the structure.

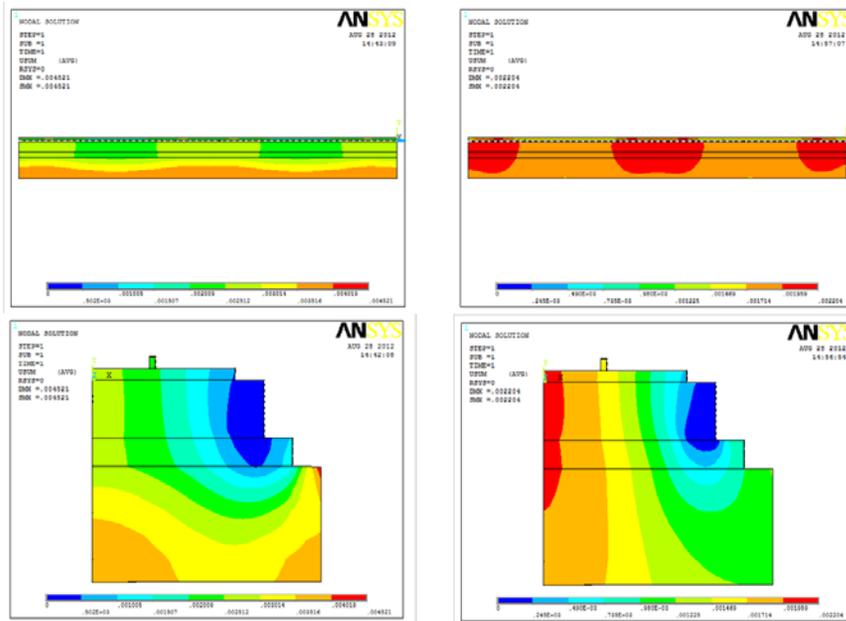


Figure 6.30
 Static model:
 magnitude of total
 displacements: soft
 soil, left; stiff soil,
 right (N.B. different
 contour scales:
 maximum is 4.5 mm
 for soft soil and
 2.2 mm for stiff soil)

DYNAMIC ANALYSES

Highlights of the dynamic analyses:

- The RAIL_TRACK and RAIL_TRAIN modules, available in LS-Dyna, were applied for approximate modelling of the train-track interaction and for the calculation of the rail-wheel contact forces
- The value of the wheel-rail contact stiffness was set to 2 MN/mm (vertical and lateral stiffness could have been specified) to agree with experimental measurements
- Hughes-Liu beam elements (2-node elements) were used to model the rails
- The wheelsets of the vehicle were explicitly modelled
- The axle load was simulated as a set of vertical forces applied at the moving vehicle-rail contact points
- Various soils (loose and dense uniform sand and stiff/soft clay) were considered in the model to investigate the effect of the change of stiffness in the substructure

A specific section of the Bulgarian line which runs between Serbia and Turkey was modelled. Data regarding the condition of the track for this site suggests the track is in a bad condition. An analysis was carried out of a laden vehicle, moving at 120 km/h over the site. The equivalent stresses in the different layers after 2.1 seconds of simulation are shown in Figure 6.32. These pictures clearly show the footpath of the train wheels in the structure and the propagation and extension of the stress field in the soil layers. Indeed for a soft soil in the subgrade evidence of the stress induced by the train is quite significant.

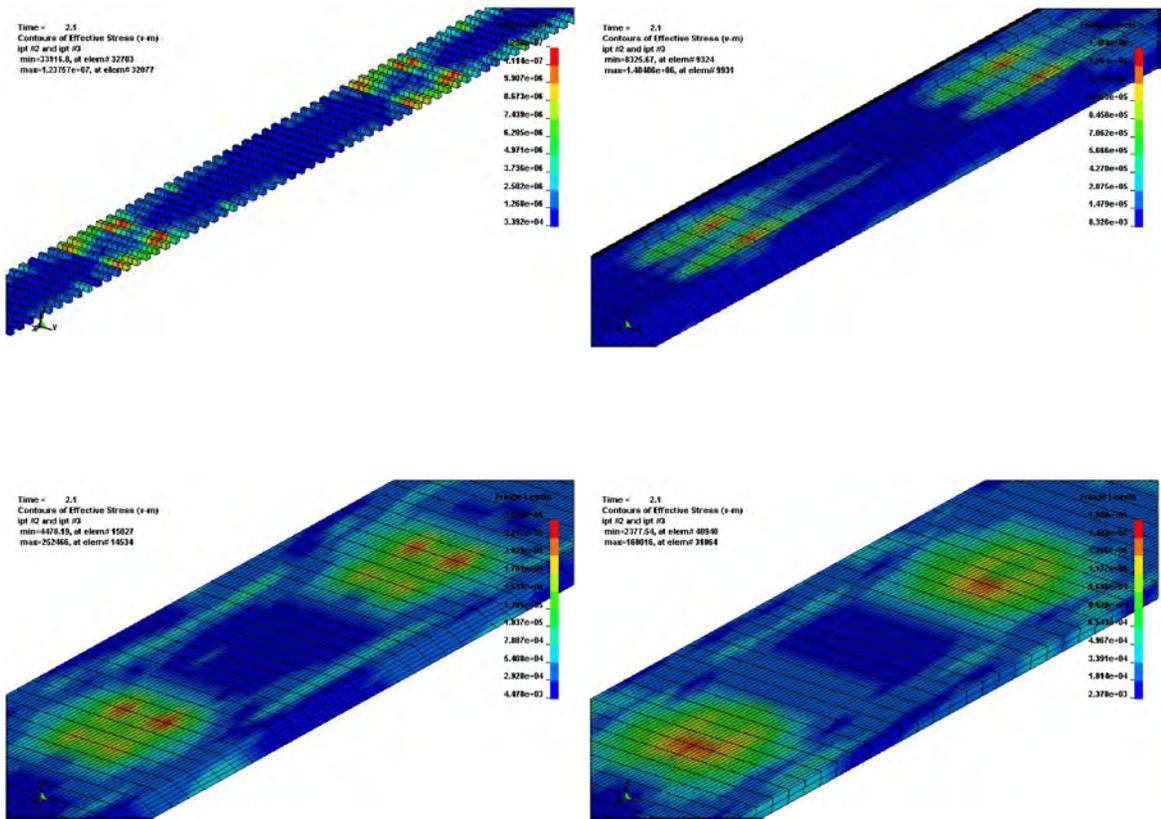


Figure 6.31

Dynamic analysis: contours of effective stress in the different layers: sleepers (top left); ballast (top right); sub-ballast (bottom left) and substrate (bottom right)

Figure 6.32 reports the variation of the resultant accelerations at different depths below the track at a certain location along the track induced by the passage of the train. It can be seen that the increased speed and axle load results in higher accelerations and peaks which are closer together, with accelerations in the ground layer increasing almost 3 times; further analysis showed that the contact stresses approximately doubled.

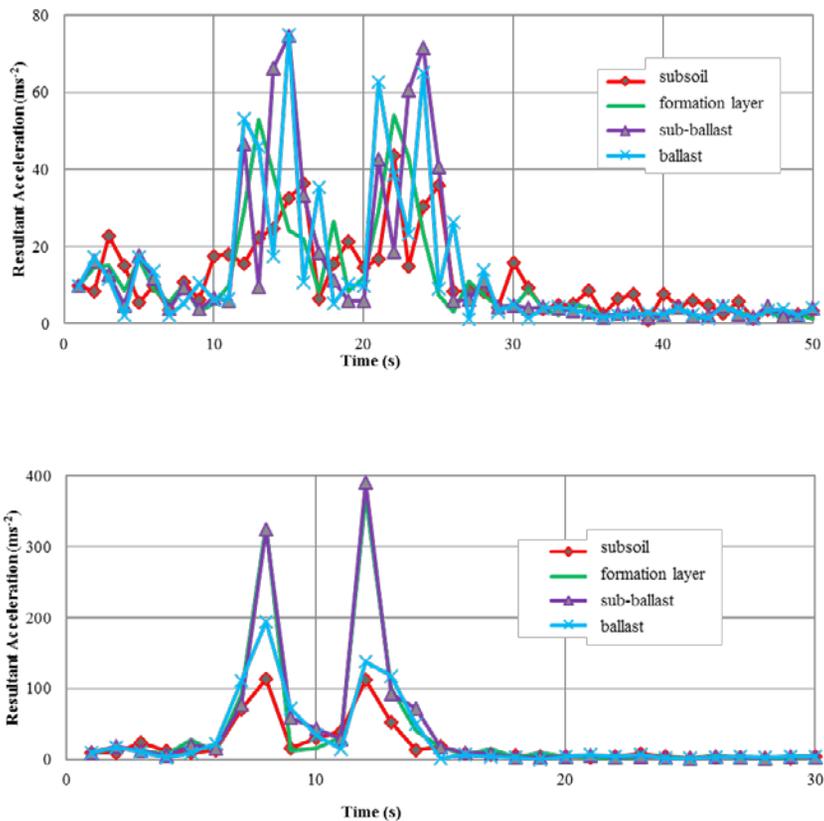


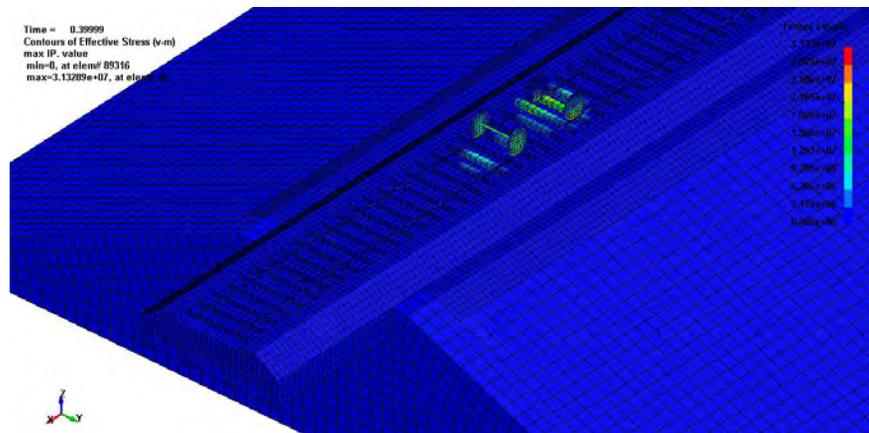
Figure 6.32
Variation of resultant accelerations at different depths below the track at a certain location along the track induced by the train travelling at speed $V=70$ km/h and axle load = 10 t (above) and $V=140$ km/h and axle load = 22.5 t (bottom)

Figure 6.33 shows a concrete bridge at the Faurei test track in Romania, one of the measurements location for the validation of the work done in the project. The model of the transition zone was based on the same layered structure as the previous model with the addition of the shoulder of the embankment, the abutment and the concrete bridge. The same approach was used for the analysis of the transition zone, with a simulation of the wheelset of the freight train passing over the bridge at various speeds and axle loads. Figure 6.34 shows the distribution of effective stresses in the structure as a wheelset approaches the bridge.

Figure 6.33
Analysis of bridge-embankment system



Figure 6.34
Distribution of effective stresses in the structure: stress concentrations are localised in correspondence of the individual wheelset position



6.4.3 EARTHWORK-STABILISING GEO-GRIDS

The use of geotextiles was studied in SUSTRAIL, not only innovations to stabilise soft ground, but also integrating sensors into them. The classical use of geotextiles in embankments on relatively soft soils is to reduce settlement and to increase the bearing capacity and slope stability. They are normally placed at the bottom of the embankment, about 50 cm above the original ground surface in one or more layers and result in a reduction of the thickness of the foundation with respect to the unreinforced case.

In recent years a new kind of foundation, the so-called “geosynthetic-reinforced and pile-supported embankment” has been developed, see Figure 6.35. Pile-like elements are placed in a regular pattern through the soft soil down to a load-bearing stratum above which a reinforcement of one or more layers of geosynthetic material (mostly geo-grids) is placed before the embankment is filled. The stress relief in the soft soil results from an arching effect in the reinforced embankment over the pile heads and the membrane effect of the geotextile.

More details in deliverable D4.2

Lead partner: TRAIN

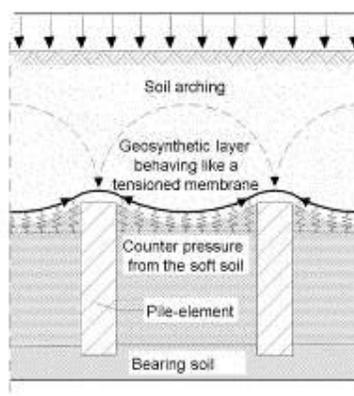
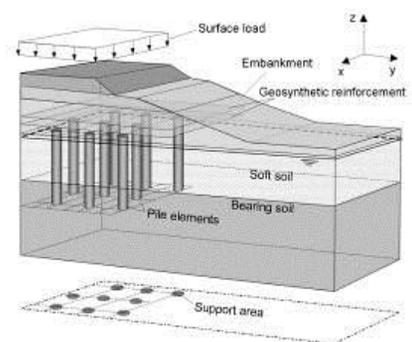


Figure 6.35
Geosynthetic-reinforced and pile-supported embankment

More details in deliverable D4.2

6.4.4 TRANSITION TO BRIDGES

Lead partner: LTU

Two aspects of railway bridges were considered in this part of the project:

Strengthening of concrete trough bridges: results presented in EC-FP6 Project Sustainable Bridges were reassessed. Near surface mounted reinforcement in which reinforcing bars are glued into grooves in the underside of the concrete have been shown to perform well, a test bridge supporting 6.5 times its design load (compared to 4.7 times without reinforcing).

The effectiveness of transition slabs: a monitoring exercise had found that there was no significant improvement in track displacement after transition slabs had been installed adjacent to a bridge in Sweden. It was suggested that under-sleeper pads may be a better alternative.

More details in deliverable D4.2

6.4.5 LONG WAVELENGTH BENDING AND OPTIMISING TRANSITIONS

Lead partner: USFD

A tool, illustrated in Figure 6.36, was developed to enable the effect of varying track stiffness to be assessed. Differential stiffness of sleeper locations was included to model the different force required to lift a sleeper compared to that to push it into the ballast.

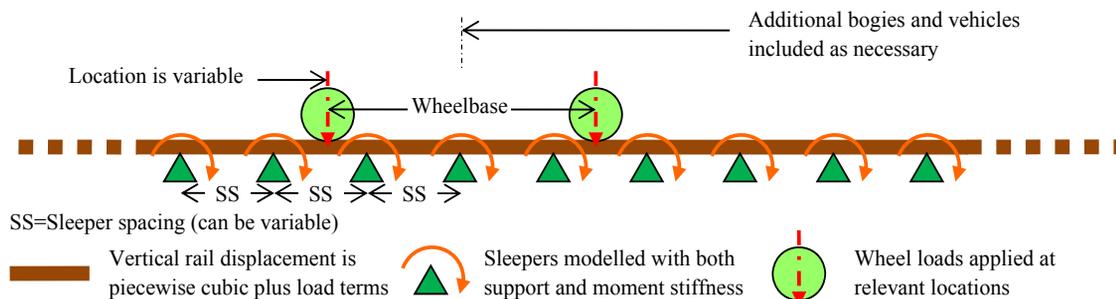


Figure 6.36
Beam model of rail

The model was used to assess various scenarios of loose and voided sleepers.

Figure 6.37 illustrates a set of results; the displacements and rail bending moments are shown for a vehicle partway onto a transition to a stiff foundation (e.g. onto a bridge). The solid green curves show the results for a uniform foundation. The transition is achieved by doubling the stiffness of only one sleeper (to 100 kN/mm) and has resulted in the increase in bending moment halving compared to there being an abrupt transition. It is also evident from Figure 6.37 that for each downward bending moment associated with a wheel load there are upward bending moments in the adjacent sleeper bay; the largest of these for this scenario occurs between vehicles, where there is the shortest distance between wheels, and has a magnitude about half that of the downward bending moment.

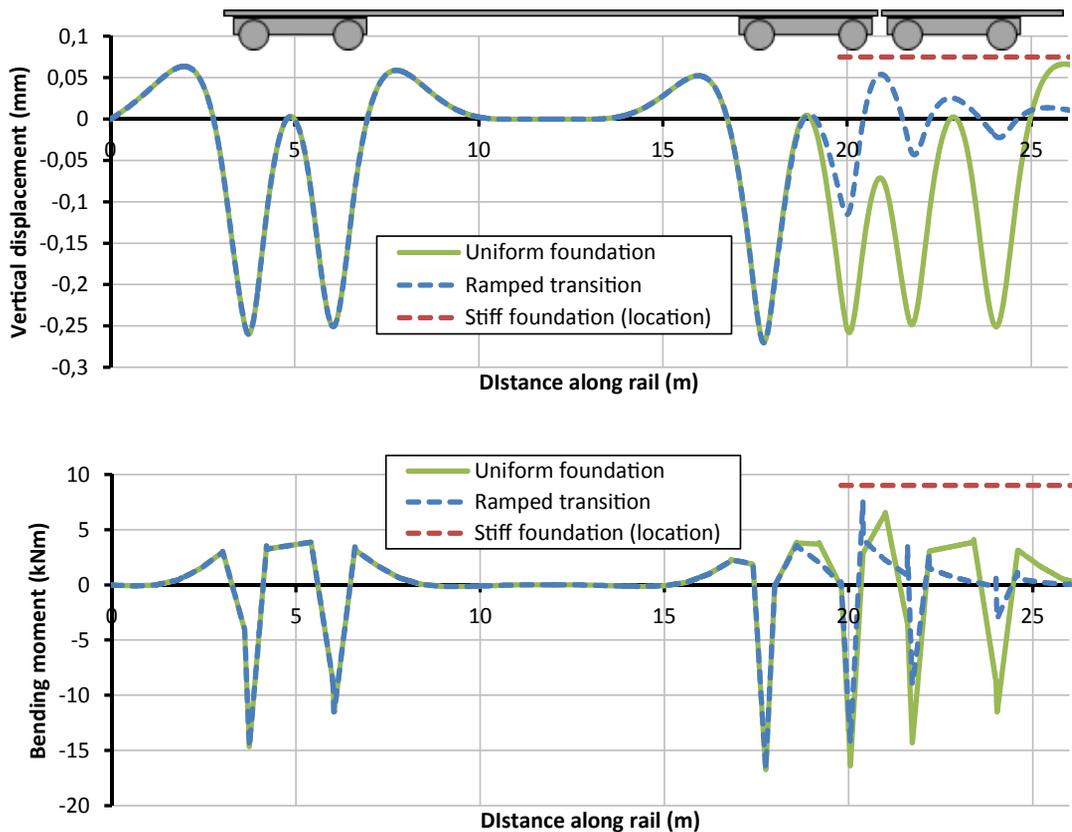


Figure 6.37
 Vehicle passing over ramped transition to stiff support

6.5 WAYSIDE CONDITION MONITORING

6.5.1 INTRODUCTION

The objective of Workpackage 4.5 was to identify monitoring tools to increase the lower bound of the track resistance probability curve through removing the causes of track failures at discrete locations with low damage resistance. The work summarized here includes identification and development of technologies that can be used to monitor infrastructure and vehicles to optimise preventative and intervention-level maintenance strategies. There are several different technologies used to measure loads imposed by vehicles on the railway infrastructure, different implementations of them, and the intervention levels and action requirements applied vary from one member state to another.

The first section of this part presents an overview of best practice, existing recommendations for imposed load limits, and a summary of a survey of axle load checkpoints (ALC). Technologies used in ALC are described, then a description of a Swedish monitoring station is followed by an analysis of data from this monitoring station. Note that geotextiles with embedded sensors (see Section 6.4.3) can also be considered to be wayside condition monitoring.

*More details in
deliverable D4.5*

*Lead partner: USFD,
MERMEC*

6.5.2 TRACK SAFETY CRITERIA

The railway track is subject to loads imposed by vehicles travelling on it causing deterioration to both the track and the wheels. In order to accommodate more traffic, and maintain safety, loads imposed on tracks must be limited. To do this they must be effectively monitored.

Much work has already been carried out by the UIC and elsewhere to define track safety criteria, but there are wide variations between the intervention levels (or alarm levels) and corresponding action requirements used by different countries. At present, no international or European set of clear recommendations for safety criteria (including measuring device precision) have been produced.

As well as identifying best practice from existing regulations and standards on track safety criteria, this task has also built upon work carried out in previous projects: InnoTrack (EU FP6 Project “Innovative track systems”), UIC Axle Load Checkpoint (ALC), UIC Harmonisation of Running behaviour and noise Measurement Sites (HRMS), and D-Rail (EU FP7 Project: “Development of the Future Rail System to Reduce the Occurrences and Impact of Derailment”). The UIC ALC project presented a state-of-the-art report on current ALC application and concluded that

their use can reduce infrastructure LCC and that there was a need for a European harmonization of limit values and actions. The goal of HRMS was to address this with the harmonization of assessment procedures and limit values for both overloaded wagons, and wheel and axle defects for rail vehicles across Europe. The D-RAIL project, aimed to identify the root causes of derailments, and proposed load limits for the prevention of derailments, particularly the ratio of horizontal force (Y) to vertical force (Q).

The use of axle load checkpoints in European countries ranged from 1 test site in Denmark to over 45 ALC installations in the Netherlands (both using the “Gotcha” system that uses fibre optic sensors to measure variation of light intensity resulting from rail bending to infer the load). Other countries using “Gotcha” included Switzerland (24 sites) and Poland (over 30 sites). The UK had 3 “Gotcha” and 28 “Wheelchex” (a system that uses strain-gauges to measure bending strains in rail) ALC installations. Spain also used “Wheelchex” with over 15 installations. Approximate numbers of ALC stations in other countries were: Sweden (27), Germany (>20), Italy (>10), Finland (8) and Norway (3).

Different sets of limits and actions are often given for wagons and drive units (locomotives and motor-driven wagons). Finland has different axle load limits (either 200 kN, 225 kN, or 250 kN) for different sections of track. Actions range from simply notifying the control centre to taking the vehicle out of service at the earliest opportunity. The axle load limits at which these actions were implemented varied for different countries as did the speed restrictions imposed on the offending vehicles until they reached either their destination or earliest point for switching out the wagon. To illustrate this variation in load limits, measurement types, and required actions enforced by different member states, the alarm levels and actions for drive units (locomotives and motor-driven rail cars) for the UK and Sweden are presented in Table 6.8 and Table 6.9 respectively. The UK levels are based only on dynamic impact load whereas Swedish ones are mainly based on peak load, but have optional limits on dynamic loads (defined as peak load minus static load) and on the ratio of dynamic load to static load. Static load has to be inferred from several readings of force and will depend on how the monitoring system performs

Alarm level (dynamic impact load)	Action(s)
250 - 275 kN	Communicated to management centre, no action required
275 - 325 kN	Out of service at destination, send to workshop
>325 kN	80 km/h speed restriction, out of service at destination, send to workshop

Table 6.8
Limits and actions - for locomotives and motor-driven rail cars (UK)

Table 6.9
Limits and actions
- for all drive units
(Sweden)

Alarm level	Action(s)
>320 kN (Peak load) or >220 kN (Dynamic load) or >5.0 (Ratio)	'Warning' : Continue to destination unrestricted but vehicle must not be used or loaded until wheel has been inspected, corrected and approved by authorized personnel
>350 kN (Peak load)	'Low' : Continue to nearest suitable location for visual inspection. If no visible wheel damage, continue to final destination with speed reduced by 20%. If visible damage, follow 'High' alarm actions.
>425 kN (Peak load)	'High' : 10 km/h speed restriction, continue to nearest suitable location where vehicle can be switched out from train.

More details in deliverable D4.5

Lead partner:
MERMEC

6.5.3 WAYSIDE LOAD MONITORING SYSTEMS

This section gives an overview of current and innovative wayside monitoring technologies able to provide data on forces. Note that the use of axle load checkpoints (ALC) can be motivated by different aims and so be operated in different ways. For infrastructure managers, the aims could be the protection of infrastructure from high loads, or potentially dangerous vehicles (for example those with a high potential for derailment), the loading on the infrastructure imposed by running vehicles, or local degradation of the infrastructure.

ALC systems can be designed to handle a very harsh environment. No moving parts and no exposed optical equipment such as cameras or lasers are needed which makes them robust in any weather. These systems have become common and are available from several vendors. It is reported that a precision better than 1% can be achieved which is ample for maintenance or safety purposes. The technological principles used for load measurement can be:

- Strain gauges: wires or conducting foils which change resistance with length. By measuring the change in resistance the strain can be estimated. Strain gauges on rails are usually positioned on the rail web or rail foot and used to study the various modes of bending and twisting of the rail as vehicles pass over.
- Load cells: Strain gauges are mounted onto a device that has known load/strain characteristics. This can be mounted directly in a load path e.g., between rail and sleeper. For accurate measurements a quite complex (expensive) installation with rigid foundations to prevent unwanted errors due to settlement of the ground is needed.

- Fibre-optic sensors: These can be used instead of strain gauges, but are usually used to study deformation over longer spans; strain gauges are used for precise measurement of strain at a point. Some ALC use optical sensors to measure the deflection of the rail between two sleepers, and determine the applied forces from this deflection.
- Laser systems: Rail deflection can be analysed using lasers. These have the benefit that they can be placed away from the track infrastructure.
- Accelerometers: These are placed on the rails and the motion of the rail is used to determine the applied forces. If the stiffness of a section of track is known precisely, then accelerometer readings can be used to estimate the forces acting on the track. A high-frequency measurement is necessary to capture details of this force. In practice, there are large uncertainties in the structural stiffness of the track and therefore analysis of forces requires careful calibration (for example stiffness changes with season and is typically affected by moisture levels and freezing).
- Piezo-resistive based clamping force sensor: this innovative technology developed during SUSTRAIL is packaged in a 'smart washer' that would be capable of monitoring the clamping force of bolted joints.

Processing the data from ALC can reveal overloading or unbalanced loading of vehicles, and wheel defects such as out-of-round wheels and wheel flats, which increase the risk of rail breaks and the consequent potential for derailment. For derailment prevention, trackside inspection of vehicle forces extends to analysis of curving behaviour and running instability as well. Checkpoints placed in curves support the analysis of curving behaviour while checkpoints placed in tangent track support analysis of skewed loading.

There can also be benefits for train operators: they can monitor the condition of individual vehicles over time; the load information about their fleet can be used for enhancing their maintenance regimes; preventative maintenance and repair can be scheduled to achieve longer life and decrease LCC. For example, a system based on depot $\Delta Q/Q$ measurement within twisted track could be adapted to form an on-track $\Delta Q/Q$ assessment. The basis of this addition would be to detect deterioration in vehicle $\Delta Q/Q$ performance relative to normal operational thresholds. Such a system would require RFID tagging functionality to store threshold $\Delta Q/Q$ values for a particular vehicle type.

It was noted that the most common on-track measuring systems are those which measure only the vertical forces. It is apparent from UK operations and also other member states that whilst these systems are typically used to identify wheel flats/ovality and axle overloading, they often are not used to look at uneven loading or low vertical loads. In some cases this data is available from the system but is not used as an alarm by the infrastructure manager (IM). It is recommended that IMs review their on-track mounted wheel load measuring systems and identify whether additional data or measures can be tracked to increase the early detection of possible increased derailment risk.

More details in deliverable D4.5

6.5.4 THE JVTC/DAMILL MONITORING STATION

Lead partner:
DAMILL, LTU

In 2006, JVTC (Luleå Railway Research Centre) decided to install a wayside monitoring station on the Swedish iron ore line Malmbanan. The goal was to support the JVTC research team with empirical data suitable for railway maintenance studies (e.g. see next Section). After some surveys on different monitoring techniques, it was clear that force measurement would be most adequate for this purpose. The force measurement system was based on traditional strain sensors put in different patterns on both rails in a curve, see Figure 6.38. No special sleepers were required and the track could withstand standard maintenance intervention such as alignment machines. The system data is uploaded to a web page and a RFID-reader was installed so all data from passing iron ore trains could be traced to a specific vehicle. The system has recently been expanded with dual RFID-readers for the new GS1 standard and the software has been gradually extended to the current status. The system is commercially available under the product name StratoForce.

Figure 6.38

Sensor positions in track. A very compact system cabinet that contains sensor electronics and optionally also computer and communication electronics is placed on the overhead line mast.



The monitoring system takes maximum benefit from the strain gauges. The following output variables are calculated after each train passage:

- Passage time
- Travel direction
- Axle speed
- Axle count
- Locomotive type
- Lateral wheel forces
- Rail vibration (Wheel generated)
- Angle of attack (AoA)
- Vehicle ID
- Wheel transients
- Dynamic wheel load
- Static wheel load

6.5.5 FORCE MEASUREMENT FOR VEHICLE ANOMALY DETECTION

More details in deliverable D4.5

Lead partner: LTU, DAMILL, USFD

This chapter presents possible vehicle defects that can be detected by a force monitoring system such as the JVTC/Damill system presented in the previous Section. It also presents typical statistics from that system. The data is used to suggest maintenance alarm limits for different parameters that are related to different vehicle defects. Maintenance alarm limits are triggered earlier than safety alarms limits and do not require such precise measurements (under normal degradation rates there is time to measure the same vehicle several times before deciding on the action to be taken). They are supposed to identify an optimal time, based on economics, when it is advisable to bring vehicles into a workshop instead of leaving them to degrade (and potentially damage track) further.

VEHICLE DEFECTS THAT CAN BE DETECTED BY FORCE MONITORING

Table 6.10 lists potential defects and describes how the force monitoring station can detect them. Detection does not imply that the exact problem can be identified by the force data alone but the listed problem will generate a change in the force profile that can trigger further inspection of the specific vehicle.

Defect	Sensors/parameter used for detection	Expected parameter reaction
Wheel out-of-roundness	Vertical forces along 3 m of track	Sinusoidal variation
Wheel flat	Vertical forces along 3 m of track	Short transients, repeated once/rev
RCF surface defect	Vertical forces along 3 m 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 3 m 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 10-30 m of track	Sinusoidal variation left/right

Table 6.10
Vehicle defects that can be detected by a StratoForce monitoring station

MAINTENANCE LIMITS BASED ON COLLECTED DATA

Data from the JVTC/Damill monitoring station provides typical values for different vehicles but using them as general values to set limits for other sites is very difficult. The curve radius, cant, humidity, lubrication, rail profiles and train speed are all factors that influence the lateral forces. It seems more adequate to use the output in relative terms and to adapt to each monitoring site.

By amalgamating the recommendations in these references and then comparing the results with data read in the JVTC/Damill system, we can find suitable levels for service limits on vehicles passing that station. Table 6.11 shows the results. Implementation of these limits on other sites can be made if first preceded by a local evaluation of their relevance.

Parameter	T or C*	UIC HRMS report		AAR MSRP	Comment
		Service	Safety	Design Criteria	
Vertical peak load [kN]	T+C	<200	<350		Reduced when 20°C below stress free temp.
Skew load, Diagonal quotient	T	<1.3	<1,7		
Skew load, left/right normally	T	<1.3	<1.7		Reduced by 20% if risk of sloshing
Skew load ,longitudinal front/rear quotient	T+C	<2	<3		
Lateral/vertical wheel load quotient Y/Q	T+C	locos <0.5-0.7 wagons <0.4-0.5	<0.8		Based on Nadal equation
Lateral/vertical wheel load quotient Y/Q, circular curve, 95% percentile	C			<0.8	Can temporarily exceed limit
Lateral/vertical axle sum quotient Y/Q, circular curve, 95% percentile	C			<1.5	Can temporarily exceed limit
Lateral/vertical wheel load quotient Y/Q, transition curve	C			<1.0	
Lateral/vertical axle sum quotient Y/Q, transition curve	C			<1.5	
Minimum wheel load, transition curves	C			>10%	
Twist/Roll, max axle sum L/V quotient	T			<1.5	
Twist/Roll, min vertical load	T			>10%	
Pitch/bounce, min vertical load	T			>10%	
Pitch/bounce, loaded spring capacity usage				<95%	
Dynamic/static wheel load quotient	T	<0.4	<0.6		
Yaw/sway lateral/vertical quotient, sum of each bogie side	T			<0.6	
Yaw/sway lateral/vertical quotient, axle sum	T			<1.5	

*: Tangent of curve

Table 6.11

Data from the UIC report HRMS and from AAR MSRP presented together with new proposals (yellow fields) of service limits for vehicles passing the JVTC/Damill monitoring station.

STATISTICAL ANALYSIS OF LOAD DATA

Data from the JVTC/Damill monitoring station has been subjected to many analyses. For example, the variation of the dynamic force with average vertical load for the wheels of a set of 2,833 steel wagons with Y25 bogies were studied. The graphs in Figure 6.39 show that there are good linear approximations for the variation of the averages and standard deviations of the lognormal distributions for the data in each load band provided loads above 60 kN (laden vehicles) are considered for the left wheel. An unexpected result is that the average left wheel dynamic forces reduce for increasing vertical load; this is probably due to the off-loading caused by curving.

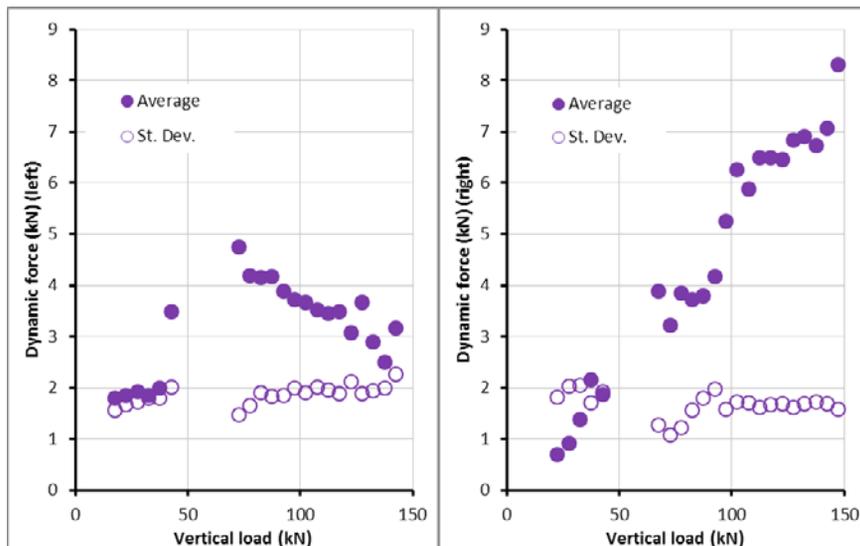


Figure 6.39
Average and standard deviations (St. Dev.) of dynamic force varying with vertical load

6.6 CHAPTER SUMMARY

This chapter presented an overview of SUSTRAIL Workpackage 4: Sustainable Track. Led by Network Rail, it included 10 partners from Universities, commercial organisations, and infrastructure operators. This workpackage aimed to improve the resilience of the infrastructure system, to reduce costs, and to improve track accessibility. Innovations that would contribute to these aims were selected by the infrastructure managers and a wide range of testing and simulation work were undertaken.

Workpackage 4 considered five aspects of sustainable track:

- factors that influence the resistance of track to the loads imposed on it
- support conditions vital to maintaining track geometry
- track systems and geometry
- switches and crossings
- track-based monitoring and limits for imposed loads

Amongst the innovations considered within Sustainable Track, four have been tested on mainline infrastructure:

- Premium Rail has been used in several trial sites in the UK on specific curves to address wear and rolling-contact fatigue issues and has been found to offer increased rail life and reduced grinding and inspection requirements.
- Earthwork-stabilising geo-textiles with inbuilt monitoring sensors have been used on an embankment at Chemnitz in Germany.
- Stiffness of under-sleeper pads have been assessed following installation on UK mainline track.
- Trackside monitoring of vehicles has been undertaken on a line in Sweden to identify wheel loading and defect issues.

Other innovations included modelling approaches and monitoring equipment that could reduce uncertainties and result in more robust maintenance regimes for track, switches and crossings, and associated structures.

DEMONSTRATION & VALIDATION OF SUSTRAIL INNOVATIONS



7. DEMONSTRATION AND VALIDATION OF SUSTRAIL INNOVATIONS

The aims of Workpackage 6 ‘Technology Demonstration’ were to “*validate a selection of the infrastructure and vehicle component upgrade solutions and technologies developed in the project ... to provide information for the analysis of the potential improvements in terms of system reliability (damage and failures, maintenance costs, etc.) and system performance and capabilities (speed, load, etc.).*”

7.1 INTRODUCTION

The workpackage included building a vehicle incorporating the SUSTRAIL innovations and designing and undertaking appropriate tests at the Faurei test track in Romania. Demonstration of most infrastructure innovations took place on other infrastructure during the project.

7.2 SUMMARY OF UPGRADES FOR DEMONSTRATION

More details in deliverable D6.1

7.2.1 SUMMARY OF VEHICLE UPGRADES FOR SUSTRAIL DEMONSTRATION

Lead partner and contributors: UVA, UNEW, LUCCHINI, KES, MERMEC

The SUSTRAIL prototype vehicle includes the innovations which were developed and analysed within Workpackage 3. The upgrades were designed or adapted from similar solutions and integrated into the flexible design of the high capacity freight wagon.

The upgrades considered for the prototype are briefly summarised in the following paragraphs, see Chapter 5 for more details.

7.2.1.1 RUNNING GEAR

The SUSTRAIL prototype bogie includes the following upgrades:

- Double Lenoir links
- Longitudinal arms
- Wheelsets with coated axle and disc brakes

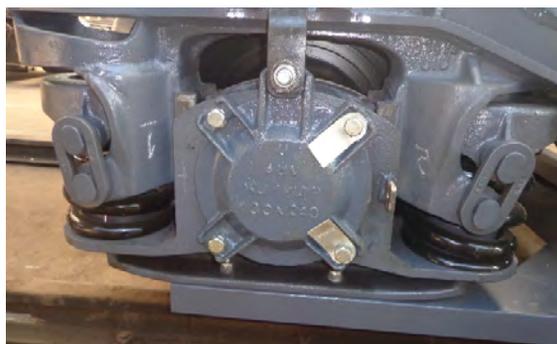


Figure 7.1
Lateral view showing the double Lenoir links



Figure 7.2
Coated axles with disc brakes and brake callipers installed on the bogie frame

7.2.1.2 BRAKING SYSTEM

The braking system was a combined system containing both brake control and wheel-slide protection functions. For higher availability and safety, separate components for the two functions were supplied, and crucial functional units of the brake control were redundantly designed.

The innovations associated with the brake system for this project are:

- The use of brake discs in freight car applications
- Adapting the distributor valve KES EDS 300 for the use in a freight car (not currently UIC homologated)
- Wheel-slide protection with axle rotation speed measurement and dump valves for freight cars (UIC homologated)
- Independent and reliable power supply for the control devices in the vehicles with axle generator and battery pack (not currently UIC homologated)

7.2.1.3 VEHICLE LIGHTWEIGHT STRUCTURE

The overall SUSTRAIL vehicle structure includes the following upgrades:

- Lightweight structural solutions using advanced steel grades (RQT701 high strength steel) and rolled profiles
- Optimised length and disposition of spigots
- Optimised components based on interoperability and commonality criteria (i.e., draw gear, coupling system and buffer gear)

See Figure 7.3 to Figure 7.6 for pictures of the vehicle.

Figure 7.3
SUSTRAIL bogie
frame





Figure 7.4
SUSTRAIL assembled bogie



Figure 7.5
SUSTRAIL wagon frame



Figure 7.6
SUSTRAIL assembled wagon

7.2.1.4 ON-BOARD MONITORING SYSTEMS

Two on-board monitoring systems have been integrated into the SUSTRAIL prototype wagon:

- Sensing system developed by partner MERMEC, including:
 - » Temperature sensors for axle box temperature monitoring
 - » Accelerometers for vehicle stability monitoring
- Sensing system for the braking system, developed by partner KES.

More details in deliverable D6.2

Lead partner and contributors: NR, AFER, TRAIN, UNEW, TATA

7.2.2 SUMMARY OF INFRASTRUCTURE UPGRADES FOR SUSTRAIL DEMONSTRATION

7.2.2.1 UPGRADES ON SELECTED SUSTRAIL ROUTES

Amongst the innovations considered within Workpackage 4: ‘Sustainable Track’, four have been tested on mainline infrastructure (see Section 7.4):

- Premium Rail has been used in several trial sites in the UK on specific curves to address wear and Rolling Contact Fatigue issues and has been found to offer increased rail life and reduced grinding and inspection requirements
- Earthwork-stabilising geotextiles with inbuilt monitoring sensors have been used on an embankment in Germany
- Under-sleeper pads have been assessed following installation on UK mainline track
- Trackside monitoring of vehicles and infrastructure has been undertaken on a line in Sweden to identify wheel loading and defect issues

These innovations are described in more detail in Chapter 6. Additionally, the rapid application sensor developed by NewRail is to be tested at the test track.

7.3 VEHICLE TESTS

More details in deliverables: D6.1, D6.3

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 that should be followed are the UIC leaflets and European standards (EN). European Standards EN 14363:2005 and EN 12663-2:2010 provide details also on the types of tests that would be required for a new or modified vehicle to be accepted.

Lead partner and contributors: AFER, UVA, UNEW, MERMEC

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 regulations, such as national standards, company standards and procedures, etc., have to be identified and applied.

In the UK, for example, new and modified rail vehicles need to comply with the Railway Group Standard GM/RT2000; this describes the procedures that would need to be complied with for design and acceptance. The UK standard for brake tests for freight vehicles is GM/RT2043.

The railway vehicle tests shall be performed to demonstrate that the vehicle design complies with the performance requirements imposed by the manufacturer and those required by the infrastructure managers. The tests shall be undertaken on the prototype vehicle built according to the new design.

The tests shall be performed under the prevailing ambient conditions unless otherwise specified. The tests are either static (laboratory tests) or dynamic (field tests) and are summarised in the following subsections.

7.3.1 LABORATORY TESTS

7.3.1.1 DIMENSIONAL TESTS

Objective: to verify that the outside dimensions of the vehicle, and any clearances and flexible connections when completely assembled and in working order, comply with the limits set out in the standards.

7.3.1.2 CONSTRUCTION GAUGE OF THE WAGON TEST

Objective: to verify that the kinematic envelope of the wagon is in accordance with the design, by the coefficient of flexibility (sway) test.

The coefficient of flexibility (**s**) is the relationship between the lateral inclination of the loaded wagon (**η**) on its suspension springs as a result of a lateral inclination of the track (**δ**).

$$s = \tan\eta/\tan\delta$$

7.3.1.3 WEIGHING TESTS

Objective: to verify that the vehicle mass and distribution comply with the limits set out by the manufacturer and includes tests for the following parameters:

- the vehicle mass
- the measured load per axle
- the measured load per wheel

7.3.1.4 FRICTION BRAKE SYSTEM TESTS

Objective: to verify that the brake system operates in accordance with the freight wagon design and give sufficient confidence that the dynamic tests may take place. The following systems shall be functionally checked statically:

- emergency brake
- service brake
- mobility of brake rigging

7.3.1.5 PARKING BRAKE SYSTEM TESTS

Objective: to verify that the parking brake system satisfies the requirements of the manufacturer.

The test criteria to demonstrate the effectiveness of the wagon parking brake system involves the vehicle remaining stationary for a limited period, held by a parking brake subject to leaks (e.g., hydraulic or air brake); the brake shall be applied with maximum force and it shall be verified during a period specified, that there is no significant fall-off in the force applied.

7.3.2 FIELD TESTS

7.3.2.1 DYNAMIC STRUCTURAL ANALYSIS OF THE VEHICLE

The test is to demonstrate the compliance with Wöhler curve of the wagon body.

7.3.2.2 BRAKING AND BRAKING THERMAL CAPACITY TESTS:

A single vehicle “slip brake test” will be performed. The test will be carried out at the following speeds:

- 100 km/h
- 120 km/h
- 140 km/h

The objective of the test is to determine the braked weight percentage (λ), by means of the average stopping distance.

After each braking test, the **thermal capacity** of the wheels and brake discs need to be determined.

7.3.2.3 EVALUATION OF THE RUNNING BEHAVIOUR OF THE VEHICLE BY MEASURING ACCELERATIONS

In these tests running safety, and ride characteristics of the vehicle are evaluated.

Running safety:

- accelerations at the bogie allow an assessment of running safety on a simplified basis
- accelerations in the vehicle body are used for the simplified assessment of running safety
- instability of the vehicle is assessed on the basis of a moving RMS value of lateral accelerations on axles

Ride characteristics:

- accelerations in the vehicle body are used for assessing ride characteristics of the vehicle; the assessment includes maximum and RMS values of accelerations

7.3.2.4 NOISE TESTS

Noise emitted by freight wagons can be either pass-by noise or *stationary noise*. Stationary noise of a freight wagon will only be of relevance if the wagon is equipped with auxiliary devices like engines, generators, or cooling systems, so is not applicable for the SUSTRAIL wagon.

Pass-by noise: the objective of the test is to determine the A-weighted equivalent continuous sound level.

More details in deliverable D6.2

7.4 INFRASTRUCTURE TESTS

Lead partner and contributors: AFER, NR, TRAIN, TATA, UNEW

The infrastructure tests were performed to demonstrate that the innovations provide the anticipated improvements to track resilience or suitable monitoring outputs. The following innovations have been used trackside in the UK, Sweden and Germany to validate their performance and therefore have not been included in the trials to be undertaken at the AFER Railway Testing Centre Faurei, Romania.

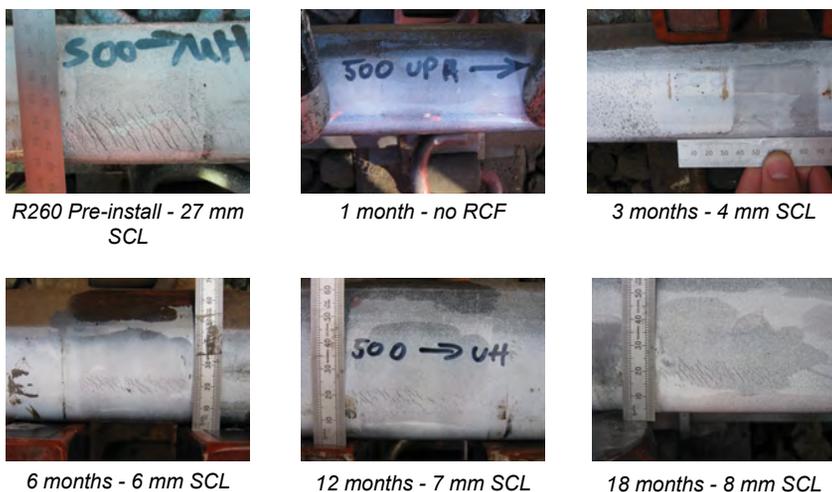
7.4.1 TESTING OF PREMIUM RAIL

HP335 has been intensively monitored at eight trial sites across the United Kingdom. Seven of those sites were in Network Rail Infrastructure, and one on a light rail system. All trial sites were chosen by the customer based on their previous degradation history and have been monitored in collaboration with the customer at regular intervals for up to four years for wear, rolling contact fatigue, corrugation, and weld performance. All trial sites have seen positive results compared to previous standard grade rails, see e.g. Figure 7.7.

Following these trials the grade was fully approved for use on Network Rail infrastructure and as of March 2015 over 600 km of HP335 rail has been supplied for installation within the United Kingdom. HP335 is designed to be used on curved track and other high duty areas where rolling contact fatigue and wear are the relevant degradation mechanisms.

Figure 7.7

Example of improved RCF resistance at an HP335 trial site



MHH is a premium heat treated rail designed for wear prone and heavy haul routes and combines high hardness of around 400HB with very low stresses in the head and foot. It has been in several trials locations including: Eurotunnel, by Deutsche Bahn, and at the Facility for Accelerated Service Testing (FAST) in America. A test site at Tata Steel Ijmuiden steelmaking facility with an axle load of 40 to 45 t has shown wear resistance around twice that of R350HT.

The grade fully complies with R370CrHT as defined in EN13764-1:2011 so adheres to European standards.

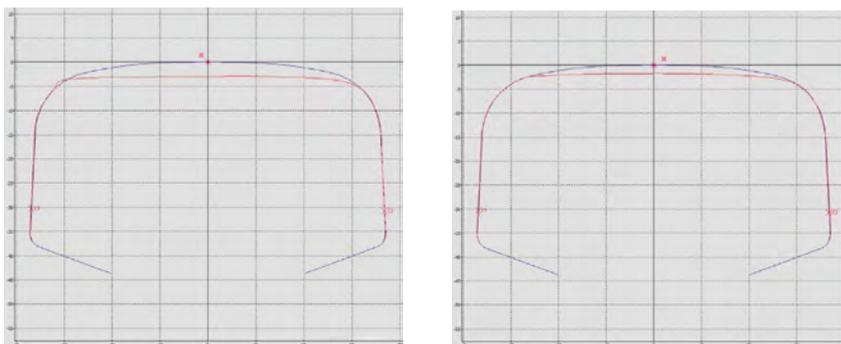


Figure 7.8
Example difference in worn profiles between R350HT (left) and MHH (right) after eight years

7.4.2 RAPID APPLICATION SENSORS AS A TOOL FOR INFRASTRUCTURE MANAGERS FOR TRACK CONDITION MONITORING AND ASSESSMENT

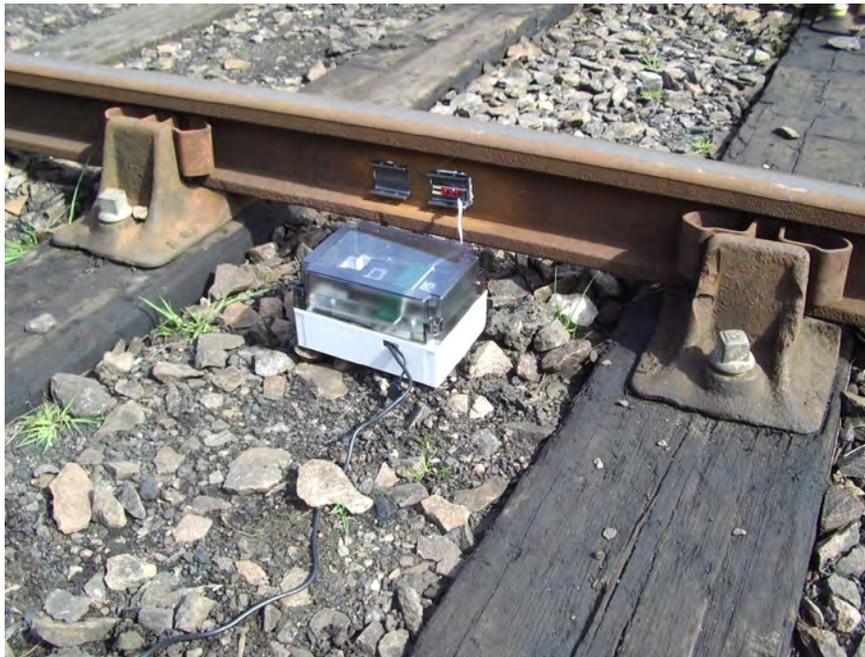
A compact and portable rapid application sensor system has been developed by partner NewRail to utilise advances in micro-processing, wireless and battery technologies to develop a system which can be applied rapidly. This allows the system to be installed between service trains and deployed almost anywhere on the network. The ability of the system to be rapidly installed without disrupting service trains and its independence from the power infrastructure make it an effective tool not only for collecting data on new track constructions or for model validation, but also as a site investigation tool to assess the performance of track and assist in identifying and resolving issues on sites where problems have been identified.

The prototype system comprises a combination accelerometer, gyroscope, and magnetometer sensor stick, which measures each of these parameters in three axis, connected to a processor with storage memory programmed to record the output from the sensor. In addition to these components there is a small battery pack to power the system and a wireless connection module

to allow the system to be set up, measurements to be initiated and stopped, and the data downloaded without the operator being at immediate risk from passing vehicles. The system could be adapted to measure other parameters by substituting different sensors and re-programming the system.

The sensor is attached to the location being measured, for example rail or sleepers, through a mounting plate which is either joint directly or firmly clamped to the measurement location. This allows the sensor to be rigidly attached to the sensor location without alteration of the location, but also allows the sensor and mounting plate to be re-used. The sensor is connected by wires to the recording equipment located in a small box placed or secured close to the sensor. A trial installation is shown in Figure 7.9.

Figure 7.9
Rapid application
sensor system
prototype



The rapid application sensor system will be used for measuring key track components on upgraded tracks and for analysing the impacts of both track and vehicle innovations on SUSTRAIL sustainable track solutions.

7.4.3 SENSOR-INTEGRATED GEOTEXTILE SYSTEM

Sensor-integrated geotextiles have been developed by partner D'Appolonia and have been considered within SUSTRAIL as a way of performing Structural Health Monitoring (SHM) of the railway infrastructure. In addition to the usual functions geotextiles perform (strengthening, filtration, stabilisation, separation, drainage) these geotextiles can undertake SHM as the result of the integration within the structure of distributed fibre-optic sensors. An efficient signal processing technique is used to process the raw sensor measurements to estimate damage size and location.

The benefits of using sensor-integrated geotextiles within the railway substructure include:

- Indicate impending failure
- Evaluate critical design assumptions
- Assess contractor's means and methods , so control construction
- Minimize damage to adjacent structures
- Provide data to help select remedial methods to fix problems
- Document performance for assessing damages
- Inform stakeholders
- Satisfy regulators
- Reduce litigation
- Advance state-of-knowledge

A series of laboratory tests of the sensor-integrated geotextiles were carried out in order to verify their behaviour under different loading scenarios; also some data from the sensors installed at a German test site was acquired. A simple test rig was prepared, as shown in Figure 7.10, where a roll of the geotextile was used. The test evaluated the strain measured by the sensor due to a load supported by the geotextile.

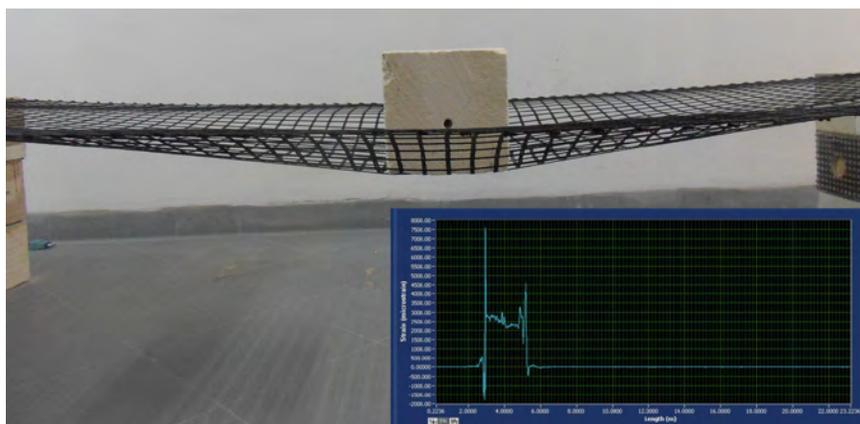


Figure 7.10
Acquisition of strain induced by an imposed load corresponding to a single stone block

In addition to the laboratory tests, a field test was performed near Chemnitz (Germany), on a route having a very high traffic volume. The portion of the embankment was more than 100 years old and has been selected since it was under reconstruction. Periodic measurements have been carried out in order to detect any movement within the embankment and its evolution during time. Figure 7.11 shows an aerial view of the location of the test.

Figure 7.11
Test site of the multifunctional geotextiles tested in SUSTRAIL (©Google maps) with sensor location



7.5 CHAPTER SUMMARY

The SUSTRAIL project is committed to improving the rail-freight system. This chapter has described how the innovations that have been studied are being demonstrated: a prototype vehicle has been built and ran on a test track to establish the viability of the vehicle innovations; key physical infrastructure innovations have been tested on track in various European contexts.

CONCLUSIONS & IMPLEMENTATION



8. CONCLUSIONS & IMPLEMENTATION

The SUSTRAIL project has achieved significant advances toward improving the competitiveness of the European rail freight industry. As would be expected from a holistic project that considered vehicles, infrastructure, and economics, there were developments in all three areas as well as developments in the enabling technologies of computer simulation, physical and computational modelling, and data and risk analysis.

8.1 VEHICLE

The major development for freight vehicles, aspects of which are the subject of a patent application, was an innovative suspension system for a bogie. Most of these innovations were based on technology existing in other modes which reduced the risk of failure in an industry which is by nature conservative. This was designed to reduce track damage and environmental impact, while allowing safe running at higher speeds than conventional freight vehicles. This was not just a theoretical advance, but was incorporated, along with a wide range of other technological innovations (including braking, condition monitoring, and materials, as described in Chapter 5), into a prototype freight vehicle. The SUSTRAIL freight vehicle has been manufactured and tested, demonstrating that the simulations developed for the project were realisable. The project also considered the business case associated with introducing such a vehicle and how to overcome barriers to its introduction.

Other vehicle innovations were studied but required further development before being tested on track. These included: ecologically friendly friction modifiers, wheelset innovations, and aerodynamic fairings.

8.2 INFRASTRUCTURE

Four infrastructure innovations were demonstrated in SUSTRAIL: novel wayside condition monitoring solutions; geo-textiles with embedded sensors to detect movement of earthworks; premium rail steels; and under-sleeper pads. The trials demonstrated benefits of the technologies. A comprehensive economic assessment was carried out to support the introduction of premium rail steels.

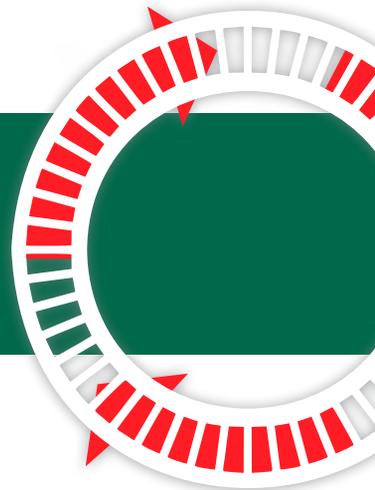
Other infrastructure innovations (described in Chapter 6) were studied:

- improved grinding strategy
- test procedures and equipment for:
 - » testing lubricants on slide plates of switches and crossings
 - » rail-joints (leading to suggestions for improvements)
- action limits and minimum action rules to optimise utilisation of rail and avoid excessive damage from traffic

8.3 IMPLEMENTATION

The key driver for the implementation of the SUSTRAIL innovations is the cost benefit at an affordable initial purchase price. However, innovations will only bring economic benefits to the railway and environmental benefits to Europe if they are used on the rail network. The homologation requirements and processes are not consistent throughout Europe and add a large cost of entry for any innovation (vehicle or infrastructure). The consequences of any introduction need to be fully considered since training, inspection, and maintenance requirements could all need revision (see Chapter 4 for more details).

APPENDICES



APPENDIX 1: PARTNERS

Throughout the book, partners are referred to by the ‘Short Name’s listed in this table.

TRAIN ¹	Consorzio per la Ricerca e lo Sviluppo di Tecnologie per il Trasporto Innovativo	Italy
NR ²	Network Rail Infrastructure Ltd	United Kingdom
NRIC	National Railway Infrastructure Company	Bulgaria
ADIF	Administrador de Infraestructuras Ferroviarias	Spain
BDZEOOD	BDZ - Tovarni Prevozi Eood	Bulgaria
LUCCHINI	Lucchini RS Spa	Italy
MERMEC	MerMec Spa	Italy
GCLAS	Gruppo Clas Srl	Italy
MARLO	Marlo AS	Norway
AFER	Autoritatea Feroviara Romana	Romania
DAMILL	Damill AB	Sweden
TATA	Tata Steel UK Limited	United Kingdom
ECOPLAN	Ecoplan Mueller, Neuenschwander, Sommer, Suter & Walter	Switzerland
VTU	Higher School of Transport - Todor Kableshkov	Bulgaria
UNEW	University of Newcastle Upon Tyne	United Kingdom
LTU	Luleå Tekniska Universitet	Sweden
MMU	The Manchester Metropolitan University	United Kingdom
TUB	Technische Universität Berlin	Germany
UNILEEDS	University of Leeds	United Kingdom
USFD	The University of Sheffield	United Kingdom
UPM	Universidad Politecnica de Madrid	Spain
KTH	Kungliga Tekniska Hoegskolan	Sweden
POLIMI	Politecnico di Milano	Italy
SPT	Petersburg State Transport University	Russian Federation
GTU	Georgian Technical University	Georgia
UIC	Union Internationale des Chemins de Fer	France
UNIFE	Union des Industries Ferroviaires Europeennes - UNIFE	Belgium
SIRV	Societatea Comerciala de Intretinere si Reparatii Vagoane de Calatori Cfr-Sirv Brasov SA	Romania
KES	Kes Keschwari Electronic Systems Gmbh & Co KG	Germany
BDZEAD	Holding Bulgarian State Railways EAD	Bulgaria
HUD	The University of Huddersfield	United Kingdom
UVA	Uzina de Vagoane Aiud	Romania

¹ The project coordinator was Donato Zangani from TRAIN who was also responsible for administrative and financial coordination

² Scientific and technical coordination was arranged by NR: this role was initially undertaken by Paul Richards, then Andrew Jablonski, and finally Kevin Blacktop

APPENDIX 2: DELIVERABLE REPORTS

Most of the deliverables of the project were dissemination reports. These are tabulated below. The dissemination status “**Status**” is indicated as PU if the report was agreed to be public (available on the website www.sustrail.eu) or CO if the report was agreed to be confidential to the consortium. However, some reports that were designated ‘confidential’ may become available; the current status will be available on the website.

WORKPACKAGE 1: BENCHMARKING

No.	Title (Number of Pages, Status)	Leader	Contributors	Partner
D1.1	Report on collected route data and benchmark methodology (21 pages, PU)	UNEW	Francis Franklin, Clare Woroniuk, Cristian Ulianov	UNEW
			Tony Whiteing	UNILEEDS
D1.2	Overview of route and track parameters (45 pages, PU)	UNEW for NRIC	Francis Franklin	UNEW
			Andrew Jablonski	NR
			Mirena Todorova	VTU, with NRIC
			Enrique Mario García Moreno	ADIF
D1.3	Overview of common freight wagon vehicles and economic data (30 pages, PU)	UNEW	Cristian Ulianov, Francis Franklin	UNEW
			Anthony Whiteing	UNILEEDS
			Andrew Jablonski	NR
			María García Santiago, Enrique Mario García Moreno, Javier Barboteo	ADIF
			Svetoslav Ivanov, Nadya Ganeva,	BDZEAD
			Armand Cojocararu	SIRV
			Ioan Buciuman	AFER
D1.4	Route summary: track characteristics, condition and economic data (56 pages, PU)	ADIF	Maria García Santiago, Enrique Mario García Moreno, David-Ibán Villalmanzo Resusta	ADIF
			Francis Franklin,	UNEW
			Andrew Jablonski	NR
			Anthony Whiteing	UNILEEDS
			Mirena Todorova	VTU, with NRIC

D1.5	Route summary: logistics, local freight market and whole system economics (66 pages, PU)	NR	Clare Woroniuk, Francis Franklin	UNEW
			Paul Richards, Stephen Kent, Andrew Jablonski	NR
			Anthony Whiteing, Phill Wheat	UNILEEDS
			María García Santiago, Enrique Mario García Moreno, José Conrado Martínez	ADIF
			Kiril Karagyozov, Todor Razmov, Mirena Todorova	VTU
D1.6	Test track assessment and performance benchmark (64 pages, PU)	AFER	Ioan Buciuman, Ion Simion	AFER
			Cristian Ulianov, Francis Franklin, Paul Hyde	UNEW
			Armand Cojocaru	SIRV
			Andrew Jablonski	NR
			Daniela Grasso	MERMEC
			Clemente Fuggini, Donato Zangani	TRAIN

WORKPACKAGE 2: DUTY REQUIREMENTS

No.	Title (Number of Pages, Status)	Leader	Contributors	Partner
D2.1	Summary of standards and externally imposed definitions of duty (84 pages + annex, PU)	UNEW	Paul Hyde, Francis Franklin	UNEW
			Andrew Jablonski	NR
			María García Santiago, Enrique Mario García Moreno	ADIF
D2.2	Future logistic requirements (73 pages, PU)	MARLO	Tilman Platz, Roland Frindik	MARLO
			Roberto Loiero, Juan Andrés Brunel Vázquez	UPM
			Dewan Islam	UNEW
			John Nellthorp	UNILEEDS
D2.3	Track design requirements for reduced maintenance (177 pages, PU)	UPM for ADIF	Roberto Loiero, Juan Andrés Brunel Vázquez, Juan de Dios Sanz Bobi	UPM
			Andrew Jablonski	NR
			María García Santiago, Enrique Mario García Moreno	ADIF
			Ed McGee, Ross Walker, Nick Coleman	TATA
			Adam Beagles, David Fletcher	USFD
			Per-Anders Jönsson, Sebastian Stichel	KTH
D2.4	Future vehicle performance requirements (89 pages, PU)	TRAIN	Donato Zangani, Valeria Bagliano	TRAIN
			Francis Franklin	UNEW
			Simon Iwnicki, Yann Bezin	HUD
			Adam Beagles	USFD
			Armand Cojocararu	SIRV
			Mahmud Keschwari	KES
D2.5	Holistic approach to the vehicle-track system (78 pages, PU)	USFD	Adam Beagles, David Fletcher	USFD
			Yann Bezin	HUD
			Andrew Jablonski	NR
			John Nellthorp, Phil Wheat	UNILEEDS

WORKPACKAGE 3: FREIGHT TRAIN OF THE FUTURE

No.	Title (Number of Pages, Status)	Leader	Contributors	Partner
D3.1	Outline design of an optimised low impact sustainable freight bogie (63 pages, CO)	HUD	Simon Iwnicki, Yann Bezin	HUD
			Anna Orlova	STP
			Per-Anders Jönsson, Sebastian Stichel	KTH
			Henning Schelle, Tobias Hermann	TUB
			Paul Hyde	UNEW
			Mahmud Keschwari	KES
			Stefano Bruni, Michele Carboni	POLIMI
			François Defossez	MERMEC
			Marco Peroni, Marco Chiudinelli	LUCCHINI
			George Tumanishvilli	GTU
			Clemente Fuggini, Donato Zangani	TRAIN
Adam Beagles	USFD			
D3.2	Hybrid locomotive (44 pages, PU)	KTH	Alija Cosic	KTH
D3.3	Outline design of a novel braking system (27 pages, CO)	KES	Frank Schneider, Mahmud Keschwari	KES
D3.4	Outline design of a novel innovative lightweight high performance freight wagon body (114 pages, CO)	UNEW	Cristian Ulianov, Francis Franklin, Ramy Shallot, Paul Hyde, Emmanuel Matsika	UNEW
			Clemente Fuggini, Donato Zangani	TRAIN
			Marius Fartan	Remarul Engineering
			Tobias Herrmann	TUB
			Rob Lambert	TATA

D3.5	Outline design of a novel innovative lightweight high performance freight vehicle bogie structure (56 pages, CO)	UNEW	Cristian Ulianov, Francis Franklin, Ramy Shaltout	UNEW
			Donato Zangani, Clemente Fuggini	TRAIN
			Marius Fartan	Remarul Engineering
			Robert Lambert	TATA
D3.6	Outline design for a condition monitoring system (22 pages, CO)	MERMEC	François Defossez	MERMEC
			Tobias Herrmann	TUB
			Stefano Bruni	POLIMI
			Simon Iwnicki	HUD
			Kevin Blacktop	NR
			Donato Zangani, Clemente Fuggini	TRAIN
D3.7	A design guide for sustainable freight vehicles (56 pages, PU)	HUD	Anna Orlova	SPT
			Mahmud Keschwari	KES
			Alija Cosic, Per-Anders Janssen, Sebastian Stichel	KTH
			Tobias Hermann	TUB
			Cristian Ulianov, Paul Hyde	UNEW
			Simon Iwnicki, Yann Bezin, Phil Shackleton	HUD
			Stefano Bruni	POLIMI
			Marco Peroni, Steven Cervello	LUCCHINI
			George Tumanishvilli	GTU
			Clemente Fuggini, Donato Zangani	TRAIN
			Phill Wheat, John Nellthorp	UNILEEDS
			Adam Beagles	USFD

WORKPACKAGE 4: SUSTAINABLE TRACK

No.	Title (Number of Pages, Status)	Leader	Contributors	Partner
D4.1	Performance based design principles for resilient track (107 pages, PU)	NR	Kevin Blacktop	NR
			Donato Zangani, Clemente Fuggini	TRAIN
			Yann Bezin, Ilaria Grossoni	HUD
			Carlos Casanueva, Per-Anders Jönsson	KTH
			Stefano Bruni, Stefano Alfi	POLIMI
			Stephen M. Famurewa, Iman Arasteh Khouy, Matti Rantatalo, Ulla Juntti, Uday Kumar	LTU
			AnVan Ho, Madassar Aslam, Robert Lambert	TATA
			Adam Beagles, David Fletcher	USFD
D4.2	Supportive ballast and substrate (53 pages, PU)	TRAIN	Donato Zangani, Clemente Fuggini	TRAIN
			Brian Whitney, Kevin Blacktop	NR
			Lennart Elfgren, Thomas Blanksvärd, Björn Täljsten, Matti Rantatalo, Ulla Juntti	LTU
			Andrew Arnall, Adam Beagles, David Fletcher	USFD
D4.3	Optimised track systems and geometry (106 pages, CO)	TRAIN	Donato Zangani, Clemente Fuggini	TRAIN
			Carlos Casanova	KTH
			Matti Rantatalo	LTU
			Yann Bezin	HUD
			Rob Lambert	TATA
			Stefano Bruni	POLIMI
			Francis Franklin, Cristian Ulianov	UNEW
Kevin Blacktop	NR			

D4.4	Optimised switch and crossings systems (213 pages, CO)	HUD	Ian Coleman, Kelvin Blacktop	NR
			Yann Bezin, Ilaria Grossoni, Sergio Neves	HUD
			Paul Hyde	UNEW
			Stefano Bruni, Stefano Alfi	POLIMI
			Matti Rantatalo, Jens Jönsson	LTU
			Madassar Aslam, Robert Lambert	TATA
			Adam Beagles, David Fletcher, Roger Lewis	USFD
			Clemente Fuggini, Donato Zangani	TRAIN
D4.5	Track based monitoring and limits for imposed loads (91 pages, PU)	MERMEC	François Defossez	MERMEC
			Crinela Pislaru	HUD
			Cristian Ulianov	UNEW
			Emma Carter	USFD
			Matti Rantatalo, Janet Lin	LTU
			Dan Larsson	Damill
			Kevin Blacktop	NR

WORKPACKAGE 5: BUSINESS CASE

No.	Title (Number of Pages, Status)	Leader	Contributors	Partner
D5.1	LCC and RAMS final report (67 pages, PU)	LTU	Matti Rantatalo, Stephen M. Famurewa Ulla Juntti	LTU
			Phillip Wheat	UNILEEDS
			Kevin Blacktop	NR

D5.2	Economic benefit final report (tba, PU)	UNILEEDS	John Nellthorp, Dan Johnson	UNILEEDS
			Juan de Dios Sanz Bobi	UPM
			Kiril Karagyozov	VTU
D5.3	Access charge final report (179 pages, PU)	UNILEEDS	Phillip Wheat, Andrew Smith	UNILEEDS
			Ani Kaushal, Simon Iwnicki	HUD
			Kristofer Odolinski	VTI
D5.4	Technical implementation final report (41 pages, PU)	NR	Kevin Blacktop	NR
			Simon Iwnicki, Crinela Pislaru	HUD
			Cristian Ulianov	UNEW
			Mahmud Keschwari	KES
			Alberto Milotti, Francesco Barontini, Carlo Vaghi	GCLAS
			François Defossez	MERMEC
			Dan Larsson	DAMIL
			Tobias Herrman	TUB
			Stefano Bruni	POLIMI
			George Tumanishvili	GTU
			Rob Lambert	TATA
			Clemente Fuggini	TRAIN
			Per-Anders Jönsson	KTH
			Ulla Juntti	LTU
			Adam Beagles, David Fletcher	USFD
			Steven Cervello	LUCCHINI
John Nellthorp, Phillip Wheat	UNILEEDS			
D5.5	Interim business case synthesis report to guide WP3 and WP4 (131 pages, PU)	UNILEEDS	John Nellthorp, Phillip Wheat	UNILEEDS
D5.6	Final business case synthesis report (tba, PU)	UNILEEDS		
D5.7	An impact analysis for operation of the optimised freight train (49 pages, PU)	GCLAS	Alberto Milotti Francesco Barontini Carlo Vaghi	GCLAS
			John Nellthorp Phillip Wheat	UNILEEDS

WORKPACKAGE 6: TECHNOLOGY DEMONSTRATION

No.	Title (Number of Pages, Status)	Leader	Contributors	Partner
D6.1	Summary of vehicle upgrade and testing (tba, CO)	AFER	Marius Ene, Ioan Buciuman	AFER
			Florentin Barbuceanu, Marius Fartan	UVA
			Cristian Ulianov, Francis Franklin, Paul Hyde	UNEW
			Stefano Cervello	LUCCHINI
			François Defossez	MERMEC
			Mahmud Keschwari	KES
D6.2	Summary of infrastructure upgrade and testing (tba, CO)	AFER	Ioan Buciuman, Marius Ene	AFER
			Kevin Blacktop	NR
			Donato Zangani, Clemente Fuggini	TRAIN
			Robert Lambert	TATA
			Cristian Ulianov, Francis Franklin, Paul Hyde	UNEW
			ADIF or other partners (e.g., DAMIL) might contribute	

WORKPACKAGE 7: DISSEMINATION AND EXPLOITATION

WORKPACKAGE 8: PROJECT COORDINATION

No.	Title (Number of Pages, Status)	Leader	Contributors	Partner
D7.1	Kickoff Material: Webpage, brochure, press release (25 pages, PU)	UIC	Bjorn Paulsson, Aymeric Boniou, Francoise El Alaoui	UIC
			Nicolas Furio	UNIFE
			Clemente Fuggini, Donato Zangani	TRAIN
D7.2	PDUK: Plan for disseminating and using the knowledge (25 pages, PU)	UIC	Laurent Schmitt, Björn Paulsson, Isabelle De Keyzer	UIC
			Nicolas Furio	UNIFE
			Clemente Fuggini, Donato Zangani	TRAIN
D7.3	Exploitable results table (19 pages, PU)	TRAIN	Clemente Fuggini, Donato Zangani	TRAIN
D8.1	Quality assurance plan (28 pages, CO)	TRAIN	Valeria Bagliano, Donato Zangani	TRAIN

APPENDIX 3: PUBLICATIONS AND PRESENTATIONS

WORKPACKAGE 1: BENCHMARKING

C Ulianov, I Buciuman, Benchmark of Freight Rolling Stock & Performance Testing, Club Feroviar Conferences: "Efficient rail freight transport for competitive logistics services", Constanța, Romania, 25-26/04/2012

Woroniuk C, A simulation model study to analyse capacity utilisation on a railway freight route in the EU, 1st International Symposium of Young Researchers, Transport Problems Conference, Katowice, Poland, 01/06/2012

WORKPACKAGE 2: DUTY REQUIREMENTS

AE Beagles, DI Fletcher, The aerodynamics of freight: approaches to save fuel by optimising the utilisation of container trains, Rail Research UK Association (RRUKA) 2012 Annual Conference, 07/11/2012

AE Beagles, Addressing the Competitiveness of Rail Freight – Engineering Challenges Related to EU Project SustRail, University of Huddersfield (UK), joint Institution of Engineering and Technology (IET), and Institution of Mechanical Engineers (IMechE) event, 07/03/2013

AE Beagles, DI Fletcher, The aerodynamics of freight: approaches to save fuel by optimising the utilisation of container trains, Journal of Rail and Rapid Transit, Institution of Mechanical Engineers, doi: 10.1177/0954409713488101
<http://pif.sagepub.com/content/early/2013/05/08/0954409713488101.abstract>, 14/05/2013

JdeD Sanz Bobi, SUSTRAIL. The sustainable freight railway: Designing the freight vehicle -track system for higher delivered tonnage with improved availability at reduced cost: the Spanish scenario under study, BcnRail, Rail Corner, 19-21/11/2013

WORKPACKAGE 3: FREIGHT TRAIN OF THE FUTURE

Y Bezin, On the use of virtual simulation for freight vehicle design development and certification – EU projects experience, "21 century rolling stock (ideas, requirements, projects)", international conference, Petersburg State Transport University, 03-07/07/2013

Rudakova E.A., Saidova A.V., Choice of interaxle linkage's parameters for using in bogies with axle box suspension with double Lenoir dampers, "21 century rolling stock (ideas, requirements, projects)", international conference, Petersburg State Transport University, 03-07/07/2013

Komarova A. N., Rudakova E. A., Review of approaches and developing method to calculate freight wagon rolling resistance, "21 century rolling stock (ideas, requirements, projects)", international conference, Petersburg State Transport University, 03-07/07/2013

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A sustainable and efficient freight transport in Europe plays a vital role in having a successful and competitive economy. Freight transport is expected to grow by some 50% (in tonne-kilometres) by 2020. However rail has, in many areas, been displaced from a dominant position as road transport services have grown and developed in capability and levels of sophistication that have not been matched by rail service providers. The SUSTRAIL project aimed to reverse this situation. As part of the 7th European Framework Programme it took a holistic approach to the rail-freight/track system and considered sustainable innovations that would allow it to regain position and market.

This concluding technical report summarises the work and provides an index into the reports on the project webpages: www.sustrail.eu

