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

SUSTRAIL

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EXECUTIVE SUMMARY

One objective of the SUSTRAIL project is to address phasing issues of the innovations designed, in order to give answers to the important question about the acceptance of rail innovations, i.e. if and under which conditions will the industry buy into the proposals coming forward from the project.

In order to ensure a successful set up of the SUSTRAIL innovations, the business plan of the deployment of the designed solutions in the market should be researched and analysed. Questions on how the new proposed service will impact the rail market and whether it will lead to environmental, commercial and social benefits in the regions need to be answered.

In this respect, the Work Package 5 produces a methodologically sound evaluation set up for the project covering all the different dimensions and fields (economics, transport effectiveness, environment, social issues) for validation. This set up ensures a neutral, objective and proper measurement of the results of the project.

The goal of Deliverable 5.7 is to assess and quantify how much SUSTRAIL impacts on the rail transport industry in terms of personnel needs. This is necessary in order to point out if the project is convenient and desirable for the society as a whole, analysing the social benefits generated by the implementation of this new solution in the long run. Results are achieved producing an evaluation matrix at the end of the Deliverable.

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, devoted to discuss with relevant stakeholders the possible impacts of a provisional list of innovations. This permitted to 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. Among the complete list of innovations, it was agreed to focus the attention of the interviewer on two main innovations on vehicles and tracks that are close to be realized on 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 and other); inspections (time needed per 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. As stated before, this list represents the starting point for the analysis of the human factors variations determined by the implementation of the SUSTRAIL innovations.

These topics were also utilized in the SUSTRAIL business case, which includes the impacts of the SUSTRAIL innovations on freight operators, infrastructure managers, end users (freight customers) and a range of 3rd parties. Changes in operations – combined with investment in new technology vehicles and track – feed through into changes in each of these

categories. On the cost side, these changes can produce net cost reductions for the industry, while on the demand side, improvements in rail freight service quality and cost can lead to increased rail mode share and revenue for the rail industry. Together, these improvements will produce a net cost impact on the industry, which will be measured using the LCC model. The results will be included in the final set of deliverables from SUSTRAIL WP5.

The outcome of the interviews gives useful provisional insights on the impacts of SUSTRAIL innovations on human factors. In particular, **the effort in maintenance and inspections will decrease**, however, it is not possible to quantify or to assess homogeneously the magnitude. The results of the interviews reflect the expectation in a **decrease in track and vehicle maintenance efforts**. In fact, this area is expected to benefit most from SUSTRAIL innovations 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 of 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 skill sets required – such as an **increase in engineer and technical skills and skills to work with computer and digital systems** – and hence it necessitates training activities to accompany the introduction of SUSTRAIL innovations.

1. INTRODUCTION

1.1 Human factor and operational issues

One objective of the SUSTRAIL project is to address phasing issues of the innovations designed, in order to give answers to the important question about the acceptance of rail innovations, i.e. if and under which conditions will the industry buy into the proposals coming forward from the project.

The analysis of phasing issues of SUSTRAIL innovations 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 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.

Hence the human factor analysis addresses to two main goals:

1. Assessing how human factors and workforce skills are influencing the implementation (phasing) of innovative solutions in the railway system, and identifying key barriers to implementation brought by human factors;
2. Assessing how innovations influence the need for human activities, e.g.
    a. Training
    b. New workforce skills
    c. Recruitment

As concerns the first goal of the analysis, results expected are qualitative, based on literature review and experts opinion.

The second goal implies a more articulated analysis, which main outcome is the assessment of the need for changes in human factors brought by SUSTRAIL innovations, responding to specific objectives e.g., :

- Assessing where and when training has to change and/or new training is needed
- Assessing which operations are most affected by changes in human factors: maintenance (also representing largest working force), inspections, monitoring
- Evaluating the impact of SUSTRAIL innovations on drivers
- Assessing social impact of SUSTRAIL innovations, as an input to Cost-Benefit analysis to be performed as a general impact assessment framework of the business case;
- Proposing a framework to update and renew human factors aspects, to keep the human factors and workforce skills correlated with the progress and implementation of innovations

Operational aspects of the freight train of the future require specific attention since higher speed, longer train length and different wheel-rail forces have significant impact on freight train operations. Changes in operations affect human factors aspects such as driver behaviour and handling need. Such aspects have to be included in the impact analysis, with indications of the human resource differentials between ex-ante and ex-post scenarios, based on the availability of relevant operation times at cross borders and terminals within the business

cases, and having as outcome the impact on freight train operations of the optimised freight train of the future including:

- access/egress to/from terminals
- cross border operations (coupling/decoupling of locomotives, train handover)
- other operations.

This subsection assesses the human factor and operational issues arising from the implementation of the innovations to be developed in WP 3 and 4. The assessment is an iterative progress and will therefore be updated during the project period in the course of the development of the innovations.

This section provides an initial assessment of major human factor and operational issues, starting with a literature review of past and ongoing research projects, and with the outcome of a preliminary survey made among stakeholders of the rail sector including national IMs and railway associations.

The list of innovations to be assessed was given in the previous two sections, concerning "Novel rail technologies, interface and track stiffness knowledge and issues" and "Novel vehicle technologies and interface issues arising" respectively.

Whilst the technical and operational specifications are still under definition in WP3 and WP4, experts have considered aspects of SUSTRAIL technological innovations in order to give opinion on general and specific aspects related to human factors.

1.2 Methodology and inputs to this analysis

The analysis was developed in two steps. This document presents the main results emerged during the entire process. The objective of study is to realize a series of interviews and to discuss the outcomes of the SUSTRAIL project in terms of effects on the human factors.

The first step of the process was completed during 2013, and consisted in a first round of interviews, devoted to discuss with relevant stakeholders the possible impacts of a provisional list of innovations. This permitted to 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. The final list of innovations was provided by other WPs during the course of the project and is presented in the present Deliverable. Among the complete list of innovations, it was agreed to focus the attention of the interviewer on two main innovations, that are close to be realized on the final phase of the project.

Interviews were realized by telephone or by direct meeting and they were focused on the collection of qualitative and quantitative inputs. A final analysis of the main outcomes of the interviews is presented at the end of the deliverable.

Some activities and dimensions are more affected by the SUSTRAIL innovations than others. The following list presents a number of dimensions that could be importantly influenced by the introduction of the SUSTRAIL innovations. This list refers to the overall innovations and represents the starting point for the analysis that will be carried out during the following chapters.

1) Maintenance activites:
    a. rail replacement
    b. track inspections
    c. transition management (measuring track stiffness)
    d. Ballast screening (cleaning)
    e. Tamping

   f. Switches and crossings repair
   g. Stress neutralization of continued welded track
   h. Sleepers and fastenings repairs and replacement
2) Inspections:
   a. Time per inspections
   b. Personnel needs
3) Ergonomics of the maintenance agents:
   a. Heavy manual labour
   b. Working positions,
   c. hot/cold conditions
   d. dangerous locations
4) Skills of the agents:
   a. New skills required
   b. Training

As stated before, this list represents the starting point for the analysis of the human factors variations determined by the implementation of the SUSTRAIL innovations.

2. SUSTRAIL INNOVATIONS: THE SUBJECT OF THE ANALYSIS

The main purpose of the Human Factor Analysis is to gather input for estimated the variations determined by SUSTRAIL innovations. In particular, it is aimed to collect qualitative assessments from experts who have insights to different areas such as maintenance and inspection activities of tracks and vehicles, railway operations, or rail human factor issues.

In the following paragraphs we present the latest list of innovations on vehicles and tracks that was taken into account by the interviewed to answer to the questionnaire.

2.1 Innovations on vehicles

This part of the project aims to develop a freight vehicle matched to the needs of providing high capacity and high reliability with increased speed and reduced damage to the railway system and to the environment.

This acitivity is devoted to identify the key areas where recent and future developments can lead to improved running behaviour resulting in reduced impact, reduced system maintenance and lower operating costs for both vehicle and track. More efficient operation will also result in reduced environmental impact and greater sustainability.

The concept design for the SUSTRAIL freight vehicle bogie presented here includes a number of significant innovations in the running gear, wheel sets, 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 increase the potential reliability and overall chances of success of the SUSTRAIL vehicle. In line with this philosophy two SUSTRAIL demonstrator vehicles are being proposed: Demonstrator 1, based on ‘optimised conventional technology’ and Demostrator 2 based on ‘innovative technology’. Both are based on the well-established ‘Y25’ type freight bogie to further reduce the risks associated with the development of a new vehicle.

The questionnaire takes into account the innovations related to Demonstrator 1‘optimised conventional technology’, which includes:

- Steering linkages.
- Modified Y25 primary springs
- Double lenoir dampers with high resistance damping material
- Axle coating
- Novel wheel steel
- Novel wheel shape
- Disk brakes
- Conventional Y25 bogie frame modified to suit the suspension and other components
- Axle monitoring through vibration measurements and acoustic emission
- Thermal sensors to monitor axle boxes

Demostrator 2 ‘Innovative Technology’ is a bogie designed that will include additional innovations:

- Centre pivot stiffness.
- Independently rotating wheels.
- Use of friction modifier at wheel.
- Lightweight bogie based on novel materials.

- Additional condition monitoring.
- Aerodynamic fairings.

2.2 Innovations on track

Sustainable Track will facilitate the need 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.

The questionnaire focuses the attention on the technology produced by Tata Steel, that has developed a "Premium Rail Steel" named HP335 that is designed to be used on curved track and other high duty areas where both RCF (Rolling Contact Fatigue) and wear are the relevant degradation mechanisms.

TATA HP335 offers increased rail life and lower life cycle costs through reduced grinding frequency, compared to standard grade rails.

This is due to its increased resistance to RCF (~4 times the cycles to crack initiation) and excellent wear resistance(5-10 times reduction).

Other innovations are identified within the "sustainable track":

What	**Innovation**
RAIL - Premium rail steel	Premium rail steel
RAIL - Rolling Contact Fatigue	Improved predictions of RCF damage
RAIL - Rolling contact fatigue – computer modelling for the different times to initiate RCF damage	Roller hardening
RAIL - Testing and analysis of welds in CWR; novel materials, technologies, etc. (with Tata) Ultrasonic testing (lab conditions on rail samples) and analysis of results - on welds and Survey of existing inspection and monitoring technologies (with MerMec).other failure areas.	Specifications/ recommendations/ guidelines for novel steels, welding processes, technologies, etc.
RAIL - Impact of profile/inclination on RCF (Romanian profile measurement at/with AFER). Potential work: Ultrasonic testing (lab conditions on various rail samples) and analysis of results. Survey of existing inspection and monitoring technologies (with MerMec).	specifications/ recommendations for new geometries or combinations (profiles, inclination, etc.), novel steel degradation, etc.
RAIL - Wheel profile measurements for track RCF estimation	Dynamic access charges

What	**Innovation**
EARTHWORKS - Analysis of multifunctional sensorized geotextiles for subgrade and embankment reinforcement and monitoring	Multifunctional sensorized geotextiles for subgrade and embankment reinforcing and monitoring

TRACK - Force information from the WID systems in Sweden and produce statistics on typical load spectra (vertical+lateral) from different trains.	Understanding what the potential is of extending track life by pinpointing and removing bad vehicles from operation.
TRACK - Geometry degradation	Optimized maintenance scheduling using novel methods for degradation prediction
S&C - Numerical modelling of the vehicle-track dynamic interaction at crossing.	Guidelines on parameters variation on wheel, track geometry, wing/crossing shape and support conditions
S&C - Test various lubricants under representative loading conditions	Improved lubrication regime for slide plates under switch rails
S&C - Dynamic smart washer - Instrumentation of complex systems (Switches) whilst in operation and with a wide range of dynamic loading –algorithms for railways	Dynamic Smart Washer that allows (through data analysis) adapting condition evaluation of complex system such as switches

Among the partners of WP5 it was decided to put the emphasis of the analysis mainly on the two innovations that will realistically realized: Premium Rail Steel and the 'optimised conventional technology'.

In particular, considering the Premium Rail Steel the analysis is focused on the technology produced by Tata Steel, named HP335, that is designed to be used on curved track and other high duty areas where both RCF (Rolling Contact Fatigue) and wear are the relevant degradation mechanisms.

TATA HP335 offers increased rail life and lower life cycle costs through reduced grinding frequency, compared to standard grade rails.

This is due to its increased resistance to RCF (~4 times the cycles to crack initiation) and excellent wear resistance (5-10 times reduction).

Considering the vehicle, the analysis will focus on the 'optimised conventional technology' because this object is close to come to the market.

3. HUMAN FACTOR ANALYSIS

3.1 Literature review and definition of rail human factors

The literature review focuses on European research projects dealing with human and operational issues arising from the implementation of innovations in the rail sector. Furthermore, literature covering topics regarding rail operations, maintenance and inspections has been identified as well in order to underpin the analysis presented.

The literature review led to the conclusion that past rail innovation project did not focus on the analysis of human factor and operational issues. However, some useful analysis has been undertaken within the INNOTRACK project[1]. Because SUSTRAIL innovations developed in WP 4 build on INNOTRACK solutions, their considerations regarding human factor issues are relevant to our analysis. In particular, INNOTRACK identified the areas where training for operational staff is required as well as the preferred medium to be employed (provision of guidelines, technical visits, etc.). INNOTRACK Deliverable 7.2.2 summarises the results and states that track staff training activities are required for technical innovations in the areas of "track support", "switches and crossings" and "rail and welding". Within the third category, a higher level of training needs is identified for "guidance on the use of different rail grades", while the implementaion of the other solutions are supposed to require lower level of training.

A methodology to analyse human factor issues due to the implementation of rail innovation has been developed in HUSARE[2] project. To our knowledge there has been no research project undertaken on European level to further develop the proposed methodology. The HUSARE methodology could apply to SUSTRAIL in order to analyse human factor and operational issues. Whilst the methodology is originally developed to analyse human factors of cross-border operations, the document recommends its application to a single infrastructure and by doing so, the analysis may be driven by the comparison of two situations, such as before and after the introduction of new technologies[3]. The HUSARE methodology is a four-steps approach that starts with the identification of specific scenarios reflecting a task or a set of task which are required to be performed during train operation or maintenance activities. The second step comprises (1) a narrative description of each scenario, (2) a hierarchical task analysis that provides detailed information about the task steps and the task agents involved in the scenario, (3) a collection of relevant data about rules, procedures, technical systems, and working practices, and (4) data on competence issues that influence the task agents performance. Steps (2) and (3) needs to be carried out for the situations before and after the introduction of track and vehicle innovations. This is necessary for the third step that requires their comparison in terms of differing rules, procedures, working practices etc. and the expected human factor issues. The fourth step aims to predict and analyse the possible human errors or failures that may occur within the scenario.

[1] INNOTRACK is a three-year project (2006-2009), funded by the European Commission's 6th framework programme, that brought together the major stakeholders in the rail sector to develop innovative solutions in the areas of track substructure, rails and welds, and switches and crossings with the goal of a 30% reduction in life cycle costs.

[2] HUSARE (2000, p. 12) in the two-years project (1998-2000), funded within the 4th framework programme. In particular, it was focused on developing a common methodology to identify and manage human factor issues arising from trans-European rail operations in order to increase their safety, efficiency, and reliability.

[3] HUSARE (2 000), p. 44.

The literature review comprises a set of further research projects and official documents that may underpin the analysis of SUSTRAIL required within subtasks 5.4.3 and 5.4.4. To this regard we identified literature to collect information within the areas of rail operations,maintenance, and human factors. The selection of the literature was focused on contributions published after 2000 with few exemptions for projects of particular interest for SUSTRAIL. Projects have been identified from various sources, among them were of particular importance a list of 717 rail research project published by SKILLRAIL and two transport research directories, i.e. the Transport Research & Innovation Portal (www.transport-research.info) and the RSSB Human Factors Library (http://www.rssbhumanfactorslibrary.co.uk/membership/login.aspx).

Relevant studies for the category covering relevant topics on rail operations include TREND (Towards new Rail freight quality and concepts in the European Network in respect to market), 2TRAIN (TRAINing of TRAIN Drivers in safety relevant issues with validated and integrated computer-based technology, 2006-2009), SKILLRAIL (Education and Training Actions for high skilled job opportunities in the railway sector 2009-2011), and other projects listed in the following table. In particular, SKILLRAIL emphasizes the future need of training due to "technological developments affecting the professional requirements related to the operation of trains and networks as well as the maintenance of rolling stock and infrastructures”.

Name of the project	Summary of the project	Relevant information/topics for SUSTRAIL	Employment category addressed by the project
2TRAIN - TRAINing of TRAIN Drivers in safety relevant issues with validated and integrated computer-based technology (2006-2009)	It developed European best-practice guidelines for an Efficient, safety enhancing, and cost-effective use of modern technologies for driver training and for the ongoing competence and performance assessment.	List and description of operational scenarios to be handled by train drivers (D 2.4.1); discussion of human factor issues for train drivers and adequate response through training (focused on safety-critical situations) (D1.2.1); details about existing training contents and technologies used in different European countries (Spain/UK included, but only passenger for UK) (Benchmarking Report).	Train driving (human factor issues and training)
ACEM-RAIL - Automated and cost effective maintenance for railway (2011-2013)	The project focuses on the track. The final goal is to reduce costs, time and resources required for maintenance activities and increase the availability of the infrastructure. The project includes both conventional and high speed lines.	State-of-art of maintenance in Railway (D 1.1); railway inspection and monitoring techniques – analysis of different approaches (D 1.2).	Maintenance and inspection
AUTOMAIN - Augmented Usage of Track by Optimisation of Maintenance, Allocation and Inspection of Railway Networks (2011-2014)	The aim of the AUTOMAIN project is to generate additional capacity of freight paths on the existing network by improving the efficiency of track maintenance to reduce the amount of time the railway is closed to traffic. This will be achieved through the development of innovative technologies and procedures in a number of areas for freight traffic .	Investigation of existing practices in rail maintenance, including Network Rail practices (D 1.1); analysis of current working practices in relation to tamping for Network Rail (D 2.2).	Maintenance
EC-DG TREN Impact assessment study on amendments to the rail access legislation in the framework of the recast of the 1st railway package (2008-2009)	Annex E: Methodology and results of the assessment of impacts on employment and safety).	List of railway employment categories; list of activities involved in cross-border operations.	Operations

EUDD*plus* - European Driver´s Desk Advanced Concept Implementation (2006-2010)	The objective of the project EUDD*plus* was to enhance a Europe wide standardisation and harmonisation of a locomotive driver's desk functional arrangement and layout, including the testing and verification of the ergonomic advantages, sub system performance and the potential economic benefits (LCC).	n.a.	Train driver
EuRoMain - European Railway Open Maintenance System (2002-2005)	EuRoMain was aimed at defining, implementing and validating a complete maintenance support system for railways, which will allow the monitoring and diagnosis of complex equipment aboard trains and inside fixed plant, establishing new standards and a new maintenance organisation in Europe.	n.a.; few material available	Maintenance
EXTRA - Thematic synthesis of transport research results. Paper 8 of 10: Human factors (2001)	Objective was to provide a structured guide to the findings and policy implications of research relating to human factors carried out in the Transport RTD Programme between 1994 and 1998.	Cluster of projects regarding "technology acceptance" that covers all modes and deals primarily with the implementation of new technologies into the transport sector.	Human factors
HINT - Human Implications of New Technologies (1997-1998)	The project intended to develop a European strategy for managing the human and organisational impacts of the new technologies likely to be implemented over the next 10-20 years, covering all modes of transport.	no documents available	Operations (human factors)
HUSARE - Human factors analysis techniques for cross-border rail operation (1998-2000)	Development of a common methodology to identify and manage human factor issues arising from (trans-European) rail operations in order to increase safety, efficiency, and reliability.	HUSARE Methodology may be (partially) applied to SUSTRAIL.	Train driving (human factor issues focused on cross-border operations)
INNOTRACK - Innovative track systems (2006-2009)	INNOTRACK has developed a multitude of innovative solutions in the areas of track substructure, rails & welds, and switches & crossings with the objective to reduce the life cycle cost of track maintenance by 30%.	Report on training needs and plan for training programmes for accompanying the implementation of INNOTRACK solutions (D 7.2.2). Maintenance cost categories analysis for European IMs (2006 data for Network Rail and Adif, see Annex U); identification of a set of principal European maintenance cost categories; results of INNOTRACK workshops of Infrastructure Maintenance Engineers:	Maintenance

		identification and priorisation of most common European track maintenance problems (Annex B + L Adif, Annex H + R NetworkRail) (D 1.4.6).	
Mainline - MAINtenance, renewaL and Improvement of rail transport iNfrastructure to reduce Economic and environmental impacts (2011-2014)	The project is aimed to adress the implications of rail traffic increase in terms of a higher rate of deterioration of elderly rail assets and the need for shorter line closures for maintenance or renewal interventions.	Current monitoring and examination practices, including Network Rail practices (D 4.1).	Inspection
RAIL - Reliability centred maintenance (RCM) Approach for Infrastructure and Logistics of Railway Operations (2001-2002)	Main objective was to develop and apply a Reliability Centred Maintenance (RCM) Approach for the Infrastructure and Logistics of railway operation.	n.a.	Maintenance
Rail training 2020 - Training needs and offers in the European railway area the next 10 - 15 years (2007)	Identification of training needs for rail staff due to legal, technological, demographic and market changes that the railways need to deal with in the coming years.	n.a.	Operations, maintenance and inspection (training)
SAFEDMI - Safe Driver Machine Interface (DMI) for ERTMS Automatic Train Control (2006-2008)	The aim is to design and develop a ERTMS-compliant safe (at least SIL2) Driver-Machine interface with safe wireless communication interfaces for configuration, safe wireless and firmware downloading and diagnostic purposes to respond to the increasing safety level needs in the Automatic Train Control systems of high-speed rail lines.	n.a.	Train driving
Saferail - Development of Novel Inspection Systems for Railway Wheelsets (2008-2011)	It seeked to minimise wheelset failures by developing and implementing a novel on-line system for the inspection of wheels and axles of moving trains, and a combined ultrasonic-electromagnetic system for faster and more reliable inspection of the quality of new and old wheelsets during their production and maintenance.	n.a.	Maintenance and inspection

SAIL - Semi Trailers in Advance Intermodal Logistics (2000-2002)	It intended to improve the intermodal transportation of semi-trailers in Europe. This project intends to increase the percentage of semi-trailers of transported by rail. The optimisation potential will be identified with a special emphasis on the interfaces of the system's elements. The worked out solutions will be practically demonstrated and evaluated on a relevant typical route in Europe.	Description of terminal operations (Final Report)	Terminal operations
SKILLRAIL - Education and Training Actions for high skilled job opportunities in the railway sector (2009-2011)	SKILLRAIL aimed to foster a better match between the human resources needs to make railways more competitive and the offer of skills coming out of the different research institutes. One of the output was the design and launching of a sustainable framework, i.e. the EURAIL “European University of Railway”, for creation, dissemination and transfer of knowledge within the railway sector.	It emphasizes the future needs of training due to "technological developments affecting the professional requirements related to the operation of trains and networks as well as the maintenance of rolling stock and infrastructures" (see Skillrail brochure, 2011); list of 717 rail research projects (D 1.3).	n.a.
SUSTRAIL Deliverable 2.3 (2012)	This deliverable is mainly oriented to the specification of track performance required, and infrastructure managers’ (IMs) needs; it includes the work of the task 2.3: Track design requirements for reduced maintenance.	Track design requirements for reduced maintenance; IMs track duty requirements: data about current maintenance strategy of the three routes in Bulgaria, Spain, and UK; examinations and monitoring or prevention operations; maintenance operations; renewal operations (D 2.3).	Maintenance (practices)
Training and staff requirements for railway staff in cross-border operations (Atkins et al., 2002)	The report is the result of a study that was sponsored by the Directorate General for Energy and Transport of the European Commission with the aim of supporting a number of policy initiatives in the second railway package.	The study investigated selection criteria, training system, etc. for rail staff involved in cross-border operations for 20 European countries (including Spain).	Cross-border operations (qualifications and training)
TREND - Towards new Rail freight quality and concepts in the European Network in respect to market (2005-2006)	The objective was to elaborate a series of specific actions that addresses the general framework proposed by the European Commission’s White Paper focused on strengthening the rail freight sector.	Comprehensive data collection of two European rail corridors affecting Bulgaria and Spain (e.g. overview of activities and processing times for cross-border operations at specific sites) (Deliverable Work Package B2).	Cross-border operations

WORKFRET - Working Cultures in the Face of Intermodal Freight Transport Systems (1997-1998)	The main objectives were to analyse existing working cultures and organisational/ managerial structures characteristics in European freight transport systems, examine implications of the integration of new technologies, new logistics and production systems, apply technology assessment tools and suggest policy measures to establish desirable, effective and efficient anthropocentric systems in the freight transport sector.	An identification of new technologies (these consists mainly of New Information and Communication Technologies) and new logistics and production systems under introduction in freight transport systems as well as a comprehensive assessment of their impacts on working cultures.	Operations (human factors)
ERA- Support Study for Human Factors Integration – Human Functions in European Railways (2013)	The aim of this project was to provide a framework that could offer a common view across Europe of human functions that are of greatest priority to railway operations.	The research work included the following: Classification and description of human functions and consideration of the potential relationships and hierarc hies between goals (including system and personal) and human functions; Identification and analysis of safety relevant activities which are associated with the human functions.	Operations (human factors)

3.2 Human factor dimensions affected

According to the analysis carried out during D5.5, some activities and dimensions are more affected by the SUSTRAIL innovations than others. The following list presents a number of dimensions that could be importantly influenced by the introduction of the SUSTRAIL innovations. This list refers to the overall innovations and represents the starting point for the analysis that will be carried out during the following chapters.

1) Maintenance activites:
    a. rail replacement
    b. track inspections
    c. transition management (measuring track stiffness)
    d. Ballast screening (cleaning)
    e. Tamping
    f. Switches and crossings repair
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    a. Heavy manual labour
    b. Working positions,
    c. hot/cold conditions
    d. dangerous locations
4) Skills of the agents:
    a. New skills required
    b. Training

As stated before, this list represents the starting point for the analysis of the human factors variations determined by the implementation of the SUSTRAIL innovations.

4. OPERATIONS

This part of the study wants to identify the main operations on which the SUSTRAIL innovations could have impact, besides the human factors. This will permit a more extensive analysis and a possible follow up of the present survey.

The analysis of the main intermodal operations is done by looking at the literature. It is necessary to define a number of perfomances and to indicate a benchmarking value for the measurement the variations produced by the implementation of the SUSTRAIL innovations. In this part of the study the analysis is devoted to the description of the performances of the main intermodal operations and to the identification of some benchmark values. This is necessary in order to estimate the variations in terms of human factos on the entire supply chain.

4.1 Literature review

The first necessary step of the present analysis is to map the operating processes that characterizes rail freight transport. A first distinction is based on the difference between **physical processes** and **administrative ones**. Every time an Intermodal Transport Unit

(ITU), or a key element of the intermodal systems or a transport mean is moved, we can speak about a physical process[4]. Otherwise, every time that we refer to booking procedures, planning and control of the vehicle and of the intermodal unit we refer to administrative processes. In this part of the study we refer to the physical processes related to the rail freight transport, in order to identify some key indicators for the measurement of the current performances within the industry. At the end of the present part of the report we will move the analysis on the operations connected with human factors, in order to restrict the area of study.

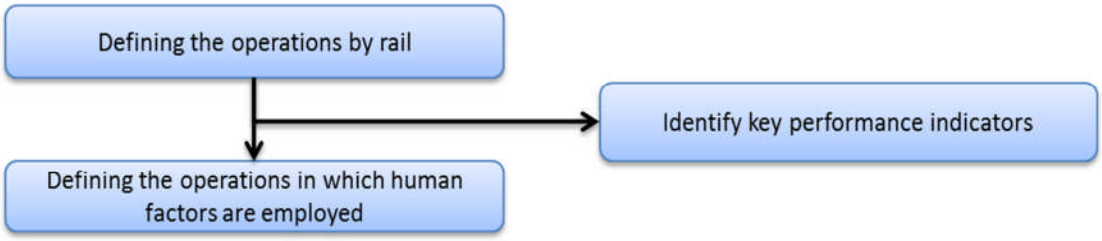

Figure 1 Logical flow of the Literature Review

Considering the intermodal operations in a rail/road terminal it is possible to identify some standard systems and operations. The project AGORA was focused on the analysis of on the **operational functions and services** and thereby the capacity of the intermodal terminals in Europe[5]. Thanks to this project it has been identified a set of standard operations and functions that is possible to find in an intermodal environment.

- Basic functions
  - Transhipment of loading units between different transport modes:
    - Rail/road
    - Road/inland navigation
    - Rail/sea
    - Sea/road
  - Terminal handling:
    - Ceck in/check out
    - Security check
- Additional Services
  - Intermediate buffer for loading units/vehicles
  - Agency functions for railways and operators
  - Storage of loading units
  - Temperature controlled
  - Trucking services
  - Container repair

The quality of the services at terminals and the efficiency of the processes have been studied by many projects at the EU level. The project "Integrated Services in the Intermodal Chain (ISIC)", was focused on the identification of a road map for the implementation of concrete actions for the improvement of the rail transport of cargo in Europe. One of these actions was the definition of measures and instruments for the improvement of the quality and performance of intermodal terminals. Hence it was developed a map of the intermodal standard sequence of physical processes in a road-to-rail terminal process.

[4] European Commission, MOSES - Motorways of the Sea European Style, May 2010, http://cordis.europa.eu/project/rcn/85688_en.html

[5] http://www.intermodal-terminals.eu/content/index_eng.html

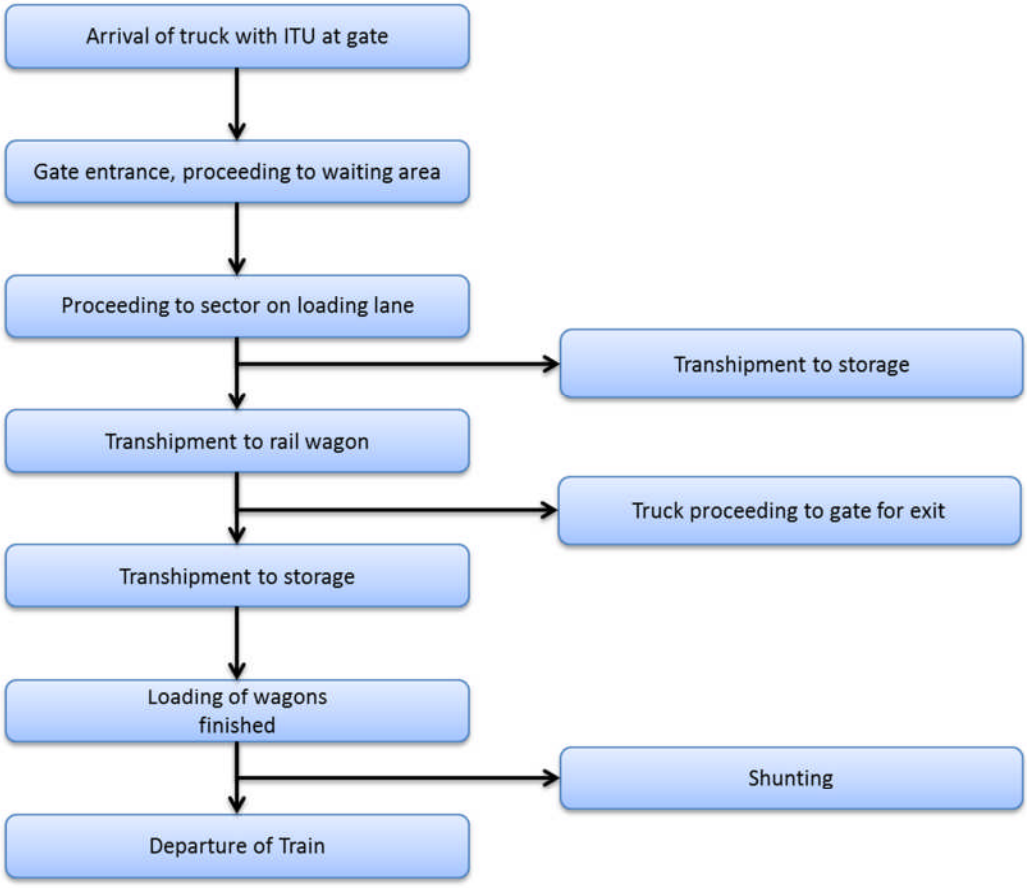

Figure 2 Standard sequence of physical processes in a road-to-rail terminal process

The following list of indicators was derived to identify some benchmark thresholds for intermodal terminals. These can be seen as most representative to describe the performance of the terminal in the road-to-rail path of processes. This can also be used in order to identify the variations produced by the SUSTRAIL innovations on the intermodal transport operations.

INDICATOR	MEASURE	REF.VALUES
Average waiting time	Minutes	19-40
Average time for positioning	Minutes	30
Average time for storage	Hours	3
Average time for transshipment	Minutes	5-60
Turnaround time for trucks	Minutes	10-60
Total waiting time for trains	Hours	5-10
Cut off time	Minutes	30-480
Trucks per hour at arrival	Number	12-15
Departures (train processed) per week	Number	30

Table 1 Key perfomance indicators developed under the ISIC project

Another interesting project for the analysis of the rail operations is “BRAVO Brenner Rail Freight Action strategy aimed at achieving a sustainable increase of intermodal transport VOlume by enhancing quality, efficiency, and system technologies”, that was published in 2007. Within this project there was an activity aimed to develop and implement a coherent

quality management system (QMS) which will measure the quality, develop key performance indicators and quality agreements and design appropriate supporting software and information tools[6].

"Quality" is essential for the development of rail freight services. Often limited to "punctuality", the Quality Manual developed within the project included operational processes and quality criteria and respective challenging quality objectives. The following list presents the quality indicators defined within the BRAVO project. They permit to analyze the rail operations and the service elements that are relevant for a market contract and that may be affected by the SUSTRAIL innovations.

1) Punctuality:
    a. 90% (with a max. tolerance of 15 min.) related to MAD (mise à disposition = time of availability)
2) Reliability
    a. Max. train delay of 180 min. related to MAD
    b. Changing of annual schedule: latest on Thursday of the prior week
3) Flexibility
    a. Cancellation of regular trains up to 48 hours prior to departure with graduated charge
    b. Interim timetable modifications within three months after submission of request
    c. Defined reaction time of the Railway Undertakings
4) Customer Information
    a. Real time monitoring of each train;
    b. Reporting on Estimated Time of Availability (ETA);
    c. Co-ordinated international reporting scheme on actual train journeys incl. train- and wagon-n°
5) Rolling Stock
    a. Monthly agreement on wagon types;
    b. 95% rate of use of agreed wagon sets
6) Transport of documents
    a. 99.9% rate of reliability of accompanying transport documents related to 1000 trips

Another interesting document for the study of the rail operations is the "Support Study for Human Factors Integration– Human Functions in European Railways", published by the European Railway Agency in 2013.Within this study, a list of the main job roles, common to international railway systems, was constructed. These are listed in the following list, and will help to identify the main rail operations that are under analysis in the present Deliverable[7].

- Train Service:
    - drivers,
    - preparers,
    - controllers,
    - crew,
    - manager,

[6] http://www.transport-research.info/web/projects/project_details.cfm?id=20342

[7] Pickup L., Ryan B., Atkinson S., Dadashi N., Golightly D., Wilson J. (2013), *Support Study for Human Factors Integration – Human Functions in European Railways*, IOE/RAIL/13/03/R, Nottingham, 27th August 2013

  - conductor,
  - steward,
  - ERTMS
- Power supply:
  - ECROs
  - Electrification
  - Pantograph
- Signaller:
  - Dispatcher,
  - despatch,
  - authorise train
  - movement,
  - LOM (Local Operating Manager),
  - MOM (Mobile Operations Manager)
  - supervisor,
  - ERTMS,
  - Train controller
- Control:
  - Train route planner,
  - Traffic manager
  - infrastructure fault control,
  - train operator.
- Station:
  - Platform manager,
  - station dispatcher
- Maintenance/infrastructure engineering:
  - Track workers,
  - COSS,
  - PICOP,
  - ES,
  - Lookout,
  - Handsignaller,
  - Supervisors,
  - S&T technicians
- Rolling stock maintenance:
  - Train maintenance,
  - rolling stock,
  - vehicle,
  - axles,
  - inspection,
  - service
- Shunters:
  - Depot,
  - yard,
  - shunting
- Level crossing:
  - Crossing keeper,
  - Level crossing operator

4.2 Operations in SUSTRAIL business case

The SUSTRAIL business case includes the impacts of the SUSTRAIL innovations on freight operators, infrastructure managers, end users (freight customers) and a range of 3rd parties (Table 2). Changes in operations – combined with investment in new technology vehicles and track – feed through into changes in each of these categories. On the cost side, these changes can produce net cost reductions for the industry, while on the demand side, improvements in rail freight service quality and cost can lead to increased rail mode share and revenue for the rail industry. Quantification of these impacts rests on the LCC (Life Cycle Cost) and RAMS (Reliability, Availability, Maintainability and Safety) modelling and the wider business case analysis being conducted in SUSTRAIL (for example, see the Interim Business Case Deliverable 5.5, Nellthorp et al 2013).

	Groups			
	IMs	**Train Operators**	**End Users**	**3rd Parties**
Impacts	- changes in costs and revenues	Freight Operators - changes in costs and revenues Passenger Operators - changes in costs and revenues	- changes in costs and benefits	Environmental Externalities - CO_2 & noise Government - grant or subsidy requirements
	⇩	⇩	⇩	⇩
	NPV, IRR financial	NPV, IRR financial	NPV	NPV

Table 2 Business Case components

Potentially the most important channels through which operational changes feed through into the business case are: maintenance and renewal procedures; operational reliability; speed; and the cost savings associated with these changes. Taking maintenance and renewals first, the RAMS simulation model incorporates:

- Failure frequencies;
- Maintenance times;
- Logistic delays;
- Maintenance activities;
- Maintenance strategies;
- Product breakdown structure (see Figure 3);
- Cost elements; and
- Life lengths of components.

Using this data, the RAMS model is able to predict the mean time between maintenance, the time spent in maintenance, and as a result the overall availability and reliability performance of the vehicle and track. Meanwhile, the LCC model produces as outputs the life cycle costs of acquisition, termination, operation and support (including maintenance) for the vehicle and track. For example, the introduction of premium rail steel is expected to increase the interval between rail grinding, and to extend the rail asset life, with implications for improved operational availability of the track. The SUSTRAIL vehicle is expected to greatly increase the maintenance interval compared with a conventional wagon, and to reduce the track

damage and associated maintenance actions. Together, these system improvements produce an increase in reliability of freight services, which impacts on end users and stimulates rail freight demand, which is represented through the freight demand model.

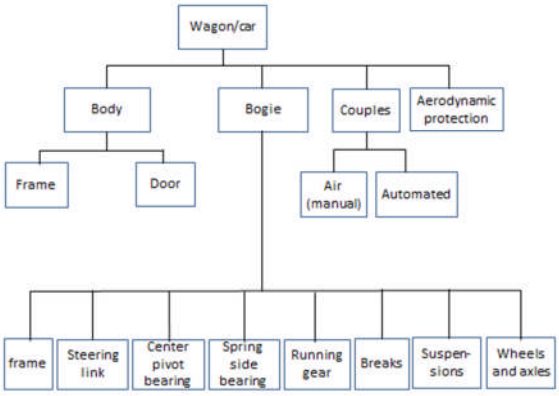

Figure 3 Product breakdown structure for the SUSTRAIL vehicle

The design of the SUSTRAIL vehicle also balances savings in the vehicle body mass against increases in bogie mass in order to accommodate disc brakes, which in turn allow for higher operational speed (e.g. 140 vs 120 kph in the UK network; and 120 vs 100kph in the Spanish and Bulgarian networks). This will bring benefits in terms of the efficient operation of the infrastructure, particularly through the availability of additional paths, which are valuable when the route is congested.

Together, these improvements will produce a net cost impact on the industry, which will be measured using the LCC model. The results will be included in the final set of deliverables from SUSTRAIL WP5.

5. SURVEY AMONG STAKEHOLDERS

This chapter presents the questionnaire that was submitted to the relevant stakeholders and the analysis that was carried out starting from the answers provided by the interviewers.

5.1 The consultations

5.1.1 The questionnaire

The interviews consisted of a series of questions that are stated in the following. Subsequently to each question, a table illustrates the inputs that have to be completed by each stakeholder. Questions were divided in three chapters: one that refers to the maintenance needs connected with rail operations, one that refers to the managerial issues in the rail transport and one that is devoted to the analysis of the impact of the entire set of innovations designed in SUSTRAIL and to possible follow up of the project.

Questions on maintenance needs:

- **Maintenability**: Please indicate how the maintenance tasks associated with the vehicles/rail could be affected by the implementation of SUSTRAIL innovations.
- **Inspectability**: How will the innovations affect the possibility to perform safety and functional inspections?
- **Accessibility**: what has to be done to gain access to the part?
- **Ergonomic**: do innovations have impact on working conditions of maintenance agents who have to work with these innovations? (E.g. working positions, vibrating tools, hot/cold surfaces, dangerous locations) In your opinion these new working conditions are better or worse?
- **Handling of maintenance**: Will these innovations set any new demands on the handling of maintenance tools and machinery? (Y/N)
- **Skills**: To support the introduction of innovations, are there new features of the task agents' skill set required and if so, for which task agents will be training required? Will these innovations require any change in maintenance personnel training?

Questions on managerial issues:

- **Maintenance strategy**: Describe the degree to which the maintenance tasks of the innovations can fit into current maintenance schedules or if new activities has to be planed? If so describe the amount of this change, hours or money?
- **Safety**: Does the implementation of innovations lead to positive or negative effects on occupational or social safety and if so, please describe the expected impacts.
- **Operations**: Provide a list of tasks related to operations (e.g. train driving, shunting, cross-border operations, freight handling, access/agress to terminals etc.) that are likely affected by the introduction of track and vehicle innovations.

  Which tasks might likely benefit from the implementation of innovations (e.g. reduction in operation times in at cross borders and terminals)?

  Are there new features of the task agents' skill set required and if so, for which task agents is likely to be training required to assist the introduction of innovations?

- **Human Interactions and barriers to the implementation:** Are the innovations improving and/or reducing the problems associated with human interaction? This includes improvements that reduce maintenance related risks, costs, improve productivity and safety?
- **Barriers to the implementation:** Do you see any barrier to the implementation of the SUSTRAIL innovations from the point of view of the human factors?

Further suggestions

- **Follow up:** Considering the entire set of innovations designed within the SUSTRAIL projects (see the attached file) have you got any other suggestion related to possible variations of human factors? Would you like to suggest other areas of investigation for the study of the impact of the project on the Human factor?

5.1.2 The list of the relevant stakeholders

Organisation	Contact person	State	Intermediate consultation	Final consultation
Network Rail	Kevin Blacktop	United Kingdom		
NRIC - ABV	Giulietta Marinova-Popova	Bulgaria		
	Borislav Pastushnaski			
	Mario Galabov			
AFER	Ioan Buciuman	Romania		
	Oana Raluca Iacob			
TRENITALIA Cargo	Domenico Miceli	Italy		
UIC	Isabelle De Keyzer	Europe		
	Christian NEVEU	Europe		
UNIFE	Nicolas Furio	Europe		
SIRV	Uzina de Vagoane Aiud	Romani		
	Armand Cojocaru			
	Gabriela Ursuly			
ERA	Susan Reinartz	Europe		

5.2 Main findings: maintenance needs and variations

5.2.1 Maintenability

The following table describes the effects of the innovations developed within the SUSTRAIL project on the inspectability of the rail transport chain.

MAINTENABILITY	Frequency	Automation	Costs
Vehicle			
Optimised Conventional Technology	Decreased (SIRV, ERA) Improved vehicle	Not applicable(NR) Unchanged(TRE)	Decreased (SIRV, ERA) Improved track life and reduced maintenance should

	should reduce track deterioration (20-30%) (NR) Unchanged(TRE)	Increased (SIRV, ERA)	provide cost reduction of (20-30%?)(NR) Unchanged(TRE)
Rail			
Premium Rail Steel	Decreased (abv, ERA) 75% reduction in grinding and improved life (NR)	Unchanged(abv) Not applicable(NR) Increased (ERA)	Increased(abv) Initial rail cost 15% higher, but installation reduces this to 5%. This is offset by reduced maintenance and inspection and improved lifesaving approximately 70%.(NR) Reduced (ERA)

Abv provided a table describing the effects of the entire set of innovations studied in WP4 on the maintenability.

MAINTENABILITY	Innovation	Frequency	Automation	Costs
RAIL - Rolling Contact Fatigue	Improved predictions of RCF damage	Decreased	Unchanged	Increased
RAIL - Rolling contact fatigue – computer modeling for the different times to initiate RCF damage	Roller hardening	Decreased	Unchanged	Decreased
RAIL - Testing and analysis of welds in CWR; novel materials, technologies, etc. (with Tata) Ultrasonic testing (lab conditions on rail samples) and analysis of results - on welds and Survey of existing inspection and monitoring technologies (with MerMec).other failure areas.	Specifications/ recommendations/ guidelines for novel steels, welding processes, technologies, etc.	Decreased	Increased	Decreased
RAIL - Impact of profile/inclination on RCF (Romanian profile measurement at/with AFER). Potential work: Ultrasonic testing (lab conditions on various rail samples) and analysis of results. Survey of existing inspection and monitoring technologies (with MerMec).	Specifications/ recommendations for new geometries or combinations (profiles, inclination, etc.), novel steel degradation, etc.	Decreased	Unchanged	Decreased
RAIL - Wheel profile measurements for track RCF estimation	Dynamic access charges	Decreased	Increased	Decreased
EARTHWORKS - Analysis of multifunctional sensorized geotextiles for subgrade and embankment reinforcement and monitoring	Multifunctional sensorized geotextiles for subgrade and embankment reinforcing and monitoring	Decreased	Increased	Increased
TRACK - Force information from the WID systems in Sweden and produce statistics on typical load spectra (vertical+lateral) from different trains.	Understanding what the potential is of extending track life by pinpointing and removing bad vehicles from operation.	Decreased	Unchanged	Decreased
TRACK - Geometry degradation	Optimized maintenance scheduling using novel methods for degradation prediction	Decreased	Increased	Decreased

MAINTENABILITY	Innovation	Frequency	Automation	Costs
S&C - Numerical modeling of the vehicle-track dynamic interaction at crossing.	Guidelines on parameters variation on wheel, track geometry, wing/crossing shape and support conditions	Decreased	Increased	Decreased
S&C - Test various lubricants under representative loading conditions	Improved lubrication regime for slide plates under switch rails	Decreased	Unchanged	Decreased
S&C - Dynamic smart washer - Instrumentation of complex systems (Switches) whilst in operation and with a wide range of dynamic loading –algorithms for railways	Dynamic Smart Washer that allows (through data analysis) adapting condition evaluation of complex system such as switches	Decreased	Unchanged	Decreased

Further suggestions were provided by Trenitalia Cargo and ERA:

Trentialia Cargo The optimized conventional technology is based on the bogie Y25 and this doesn't represent an innovation. Furthermore in the rail industry the maintainability is very centralized, since a small number of enterprises owns the majority of the vehicles. Many times the maintenance of a wagon is based on a time provision and not on the km traveled.
ERA The most important advantage is provided by the monitoring systems. According to the quality of the data that are provided (the ERMTS experience is relevant), it is possible to imagine a great impact (and often positive) in terms of frequency, quality and efficiency of the maintenance activities. This should be managed within the transport operators according to their industrial relationships. Particularly in the improvement of working conditions for the staff in accessing the information – it can be displayed remotely rather than requiring checks/data collection directly on the RS or Infrastructure (outside working in all weather conditions, difficult working postures).

5.2.2 Inspectability:

The following table describes the effects of the innovations developed within the SUSTRAIL project on the inspectability of the rail transport chain.

INSPECTABILITY	Safety	Efficiency	Costs	Frequency	Time
Vehicle					
Optimised Conventional Technology	Unchanged (SIRV) Inspection process unchanged(NR) Unchanged(TRE, ERA)	Increased(SIRV) Inspection process unchanged(NR) Unchanged(TRE, ERA)	Decreased(SIRV) 20-30% reduction in inspection (NR) Unchanged(TRE, ERA)	Decreased(SIRV) Improved vehicle should reduce track inspection (20-30%)(NR) Unchanged(TRE, ERA)	Decreased(SIRV) Inspection process unchanged(NR) Unchanged(TRE, ERA)
Rail					
Premium Rail Steel	Unchanged (ERA) Increased (abv) Inspection process	Unchanged(ERA) Increased (abv) Inspection process	Unchanged(abv, ERA) 50% reduction(NR)	Unchanged(abv, ERA) 50% reduction(NR)	Unchanged(abv, ERA) Inspection process unchanged(NR)

	unchanged(NR)	unchanged(NR)			

Abv provided a table describing the effects of the entire set of innovations studied in WP4 on the inspectability.

INSPECTABILITY	Innovation	Safety	Efficiency	Costs	Frequency	Time
RAIL - Rolling Contact Fatigue	Improved predictions of RCF damage	Increased	Decreased	Unchanged	Unchanged	Unchanged
RAIL - Rolling contact fatigue – computer modeling for the different times to initiate RCF damage	Roller hardening	Increased	Increased	Unchanged	Unchanged	Unchanged
RAIL - Testing and analysis of welds in CWR; novel materials, technologies, etc. (with Tata) Ultrasonic testing (lab conditions on rail samples) and analysis of results - on welds and Survey of existing inspection and monitoring technologies (with MerMec).other failure areas.	Specifications / recommendations/ guidelines for novel steels, welding processes, technologies, etc.	Increased	Increased	Unchanged	Unchanged	Unchanged
RAIL - Impact of profile/inclination on RCF (Romanian profile measurement at/with AFER). Potential work: Ultrasonic testing (lab conditions on various rail samples) and analysis of results. Survey of existing inspection and monitoring technologies (with MerMec).	Specifications / recommendations for new geometries or combinations (profiles, inclination, etc.), novel steel degradation, etc.	Increased	Increased	Unchanged	Unchanged	Unchanged
RAIL - Wheel profile measurements for track RCF estimation	Dynamic access charges	Increased	Increased	Unchanged	Unchanged	Unchanged
EARTHWORKS - Analysis of multifunctional sensorized geotextiles for subgrade and embankment reinforcement and monitoring	Multifunctional sensorized geotextiles for subgrade and embankment reinforcing and monitoring	Increased	Increased	Decreased	Decreased	Decreased
TRACK - Force information from the WID systems in Sweden and produce statistics on typical load spectra (vertical+lateral) from different trains.	Understanding what the potential is of extending track life by pinpointing and removing bad vehicles from operation.	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged
TRACK - Geometry degradation	Optimized maintenance	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged

INSPECTABILITY	Innovation	Safety	Efficiency	Costs	Frequency	Time
	scheduling using novel methods for degradation prediction					
S&C - Numerical modeling of the vehicle-track dynamic interaction at crossing.	Guidelines on parameters variation on wheel, track geometry, wing/crossing shape and support conditions	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged
S&C - Test various lubricants under representative loading conditions	Improved lubrication regime for slide plates under switch rails	Unchanged	Decreased	Unchanged	Unchanged	Unchanged
S&C - Dynamic smart washer - Instrumentation of complex systems (Switches) whilst in operation and with a wide range of dynamic loading –algorithms for railways	Dynamic Smart Washer that allows (through data analysis) adapting condition evaluation of complex system such as switches	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged

Further suggestions were provided by Trenitalia Cargo and ERA:

Trenitalia Cargo Innovations are required in order to simplify the structure of the bogie and to clear the space under the wagon.
ERA An important issue that has to be underlined is connected with the design of the innovations. In order to increase the efficiency and the safety of the maintenance and inspective activities the design of the new technologies has to be based considering at the heart the human factors. If a technology is developed starting from the human needs and exigencies than important advantages will be produced under the point of view of the inspectability, but also considering the accessibility, the ergonomic and the entire Life Cycle Cost of the rail assets.

5.2.3 Accessibility

The following table describes the effects of the innovations developed within the SUSTRAIL project on the accessibility of the rail transport chain.

ACCESSIBILITY	Efficiency	Costs
Vehicle		
Optimised Conventional Technology	Unchanged(SIRV) No impact on rail	Unchanged(SIRV) Not applicable(NR)

	accessibility(NR) Unchanged(TRE, ERA)	Unchanged(TRE, ERA)
Rail		
Premium Rail Steel	Unchanged (abv, ERA) No change over standard rai(NR)	Unchanged (abv, ERA) Initial rail cost is 15% higher, but overall installation cost reduces this to 5%.(NR)

Abv provided a table describing the effects of the entire set of innovations studied in WP4 on the inspectability.

ACCESSIBILITY	Innovation	Efficiency	Costs
RAIL - Premium rail steel	Premium rail steel	Unchanged	Unchanged
RAIL - Rolling Contact Fatigue	Improved predictions of RCF damage	Unchanged	Unchanged
RAIL - Rolling contact fatigue – computer modeling for the different times to initiate RCF damage	Roller hardening	Unchanged	Unchanged
RAIL - Testing and analysis of welds in CWR; novel materials, technologies, etc. (with Tata) Ultrasonic testing (lab conditions on rail samples) and analysis of results - on welds and Survey of existing inspection and monitoring technologies (with MerMec).other failure areas.	Specifications/ recommendations/ guidelines for novel steels, welding processes, technologies, etc.	Unchanged	Unchanged
RAIL - Impact of profile/inclination on RCF (Romanian profile measurement at/with AFER). Potential work: Ultrasonic testing (lab conditions on various rail samples) and analysis of results. Survey of existing inspection and monitoring technologies (with MerMec).	Specifications/ recommendations for new geometries or combinations (profiles, inclination, etc.), novel steel degradation, etc.	Unchanged	Unchanged
RAIL - Wheel profile measurements for track RCF estimation	Dynamic access charges	Unchanged	Unchanged
EARTHWORKS - Analysis of multifunctional sensorized geotextiles for subgrade and embankment reinforcement and monitoring	Multifunctional sensorized geotextiles for subgrade and embankment reinforcing and monitoring	Decreased	Decreased
TRACK - Force information from the WID systems in Sweden and produce statistics on typical load spectra (vertical+lateral) from different trains.	Understanding what the potential is of extending track life by pinpointing and removing bad vehicles from operation.	Unchanged	Unchanged
TRACK - Geometry degradation	Optimized maintenance scheduling using novel methods for degradation prediction	Unchanged	Unchanged
S&C - Numerical modeling of the vehicle-track dynamic interaction at crossing.	Guidelines on parameters variation on wheel, track geometry, wing/crossing shape and support conditions	Unchanged	Unchanged
S&C - Test various lubricants under representative loading conditions	Improved lubrication regime for slide plates under switch rails	Increased	Decreased
S&C - Dynamic smart washer - Instrumentation of complex systems (Switches) whilst in operation and with a wide range of dynamic loading –algorithms for railways	Dynamic Smart Washer that allows (through data analysis) adapting condition evaluation of complex system such as switches	Unchanged	Unchanged

Further suggestions were provided by Trenitalia Cargo and ERA:

Trenitalia Cargo Accessibility is independent from technological innovations but is dependent to the regulation
ERA An important issue that has to be underlined is connected with the design of the innovations. In order to increase the efficiency and the safety of the maintenance and inspective activities the design of the new technologies has to be based considering at the heart the human factors. If a technology is developed starting from the human needs and requirements then important advantages will be produced under the point of view of the inspectability, but also considering the accessibility, the ergonomic and the entire Life Cycle Cost of the rail assets.

5.2.4 Ergonomic

The following table describes the effects of the innovations developed within the SUSTRAIL project on the accessibility of the rail transport chain.

ERGONOMIC OF MAINTENANCE AGENTS	Working positions	Dangerous locations
Vehicle		
Optimised Conventional Technology	Unchanged(SIRV, ERA) No change over standard rail(NR) Unchanged(TRE)	Unchanged(SIRV, ERA) No change over standard rail(NR) Unchanged(TRE)
Rail		
Premium Rail Steel	Unchanged (Abv, ERA) No change over standard rail(NR)	Unchanged(Abv, ERA) No change over standard rail(NR)

Abv provided a table describing the effects of the entire set of innovations studied in WP4 on the ergonomic of the maintenance agents.

ERGONOMIC OF MAINTENANCE AGENTS	Innovation	Working positions	Dangerous locations
RAIL - Rolling Contact Fatigue	Improved predictions of RCF damage	Unchanged	Unchanged
RAIL - Rolling contact fatigue – computer modeling for the different times to initiate RCF damage	Roller hardening	Unchanged	Unchanged
RAIL - Testing and analysis of welds in CWR; novel materials, technologies, etc. (with Tata) Ultrasonic testing (lab conditions on rail samples) and analysis of results - on welds and Survey of existing inspection and monitoring technologies (with MerMec).other failure areas.	Specifications/ recommendations/ guidelines for novel steels, welding processes, technologies, etc.	Decreased	Decreased
RAIL - Impact of profile/inclination on RCF (Romanian profile measurement at/with AFER). Potential work: Ultrasonic testing (lab conditions on various rail samples) and analysis of results. Survey of existing inspection and monitoring technologies (with	Specifications/ recommendations for new geometries or combinations (profiles, inclination, etc.), novel steel degradation, etc.	Unchanged	Unchanged

ERGONOMIC OF MAINTENANCE AGENTS	Innovation	Working positions	Dangerous locations
MerMec).			
RAIL - Wheel profile measurements for track RCF estimation	Dynamic access charges	Unchanged	Unchanged
EARTHWORKS - Analysis of multifunctional sensorized geotextiles for subgrade and embankment reinforcement and monitoring	Multifunctional sensorized geotextiles for subgrade and embankment reinforcing and monitoring	Decreased	Decreased
TRACK - Force information from the WID systems in Sweden and produce statistics on typical load spectra (vertical+lateral) from different trains.	Understanding what the potential is of extending track life by pinpointing and removing bad vehicles from operation.	Unchanged	Unchanged
TRACK - Geometry degradation	Optimized maintenance scheduling using novel methods for degradation prediction	Unchanged	Unchanged
S&C - Numerical modeling of the vehicle-track dynamic interaction at crossing.	Guidelines on parameters variation on wheel, track geometry, wing/crossing shape and support conditions	Unchanged	Unchanged
S&C - Test various lubricants under representative loading conditions	Improved lubrication regime for slide plates under switch rails	Decreased	Decreased
S&C - Dynamic smart washer - Instrumentation of complex systems (Switches) whilst in operation and with a wide range of dynamic loading –algorithms for railways	Dynamic Smart Washer that allows (through data analysis) adapting condition evaluation of complex system such as switches	Decreased	Decreased

Further suggestions were provided by Trenitalia Cargo and ERA:

Trenitalia Cargo Innovations are required in order to simplify the structure of the bogie and to clear the space under the wagon.
ERA An important issue that has to be underlined is connected with the design of the innovations. In order to increase the efficiency and the safety of the maintenance and inspective activities the design of the new technologies has to be based considering at the heart the human factors. If a technology is developed starting from the human needs and requirements then important advantages will be produced under the point of view of the inspectability, but also considering the accessibility, the ergonomic and the entire Life Cycle Cost of the rail assets. Particularly in the improvement of working conditions for the staff in accessing the information – it can be displayed remotely rather than requiring checks/data collection directly on the RS or Infrastructure (outside working in all weather conditions, difficult working postures).

5.2.5 Handling of maintenance

The following table describes the effects of the innovations developed within the SUSTRAIL project in terms of new tools and machinery to cover the maintenance needs of the rail industry.

HANDLING OF MAINTENANCE TOOLS	New tools	New Machinery
Vehicle		
Optimised Conventional Technology	Yes: electronical devices(SIRV)	No(SIRV) Not applicable(NR)

	Not applicable(NR) Unchanged(TRE, ERA)	Unchanged(TRE, ERA)
Rail		
Premium Rail Steel	Unchanged (abv, ERA) New weld repair techniques required, but equipment is the same(NR)	Unchanged (Abv, ERA) Not applicable(NR)

Abv provided a table describing the effects of the entire set of innovations studied in WP4 on the ergonomic of the maintenance agents.

HANDLING OF MAINTENANCE TOOLS	Innovation	New tools	New Machinery
RAIL - Rolling Contact Fatigue	Improved predictions of RCF damage	Unchanged	Unchanged
RAIL - Rolling contact fatigue – computer modeling for the different times to initiate RCF damage	Roller hardening	Unchanged	Unchanged
RAIL - Testing and analysis of welds in CWR; novel materials, technologies, etc. (with Tata) Ultrasonic testing (lab conditions on rail samples) and analysis of results - on welds and Survey of existing inspection and monitoring technologies (with MerMec).other failure areas.	Specifications/ recommendations/ guidelines for novel steels, welding processes, technologies, etc.	Y	Y
RAIL - Impact of profile/inclination on RCF (Romanian profile measurement at/with AFER). Potential work: Ultrasonic testing (lab conditions on various rail samples) and analysis of results. Survey of existing inspection and monitoring technologies (with MerMec).	Specifications/ recommendations for new geometries or combinations (profiles, inclination, etc.), novel steel degradation, etc.	Unchanged	Unchanged
RAIL - Wheel profile measurements for track RCF estimation	Dynamic access charges	Unchanged	Unchanged
EARTHWORKS - Analysis of multifunctional sensorized geotextiles for subgrade and embankment reinforcement and monitoring	Multifunctional sensorized geotextiles for subgrade and embankment reinforcing and monitoring	Y	Y
TRACK - Force information from the WID systems in Sweden and produce statistics on typical load spectra (vertical+lateral) from different trains.	Understanding what the potential is of extending track life by pinpointing and removing bad vehicles from operation.	Unchanged	Unchanged
TRACK - Geometry degradation	Optimized maintenance scheduling using novel methods for degradation prediction	Unchanged	Unchanged
S&C - Numerical modeling of the vehicle-track dynamic interaction at crossing.	Guidelines on parameters variation on wheel, track geometry, wing/crossing shape and support conditions	Unchanged	Unchanged
S&C - Test various lubricants under representative loading conditions	Improved lubrication regime for slide plates under switch rails	Unchanged	Unchanged

HANDLING OF MAINTENANCE TOOLS	Innovation	New tools	New Machinery
S&C - Dynamic smart washer - Instrumentation of complex systems (Switches) whilst in operation and with a wide range of dynamic loading – algorithms for railways	Dynamic Smart Washer that allows (through data analysis) adapting condition evaluation of complex system such as switches	Unchanged	Unchanged

5.2.6 Skills

The following table describes the effects of the innovations developed within the SUSTRAIL project in terms of new skills required for the maintenance agents.

SKILLS	Training	New personnel	Qualifications	Costs
Vehicle				
Optimised Conventional Technology	Increased(SIRV, ERA) Not applicable(NR) Unchanged (TRE)	Unchanged(SIRV, TRE) Not applicable(NR) Reduced (ERA)	Increased(SIRV, ERA) Not applicable(NR) Unchanged (TRE)	Unchanged(SIRV, TRE) Not applicable(NR) Increased (ERA)
Rail				
Premium Rail Steel	Unchanged (Abv) Identify new material and New weld techniques, covered by training course (2 days). (NR) Increased (ERA)	Unchanged (Abv) Identify new material and New weld techniques. (NR) Reduced (ERA)	Increased (Abv, ERA) Add to track worker training on welding. (NR)	Unchanged(Abv) Increased (ERA)

Abv provided a table describing the effects of the entire set of innovations studied in WP4 on the ergonomic of the maintenance agents.

SKILLS	Innovation	Training	New personnel	Qualifications	Costs
RAIL - Premium rail steel	Premium rail steel	Unchanged	Unchanged	Increased	Unchanged
RAIL - Rolling Contact Fatigue	Improved predictions of RCF damage	Increased	Unchanged	Increased	Unchanged
RAIL - Rolling contact fatigue – computer modeling for the different times to initiate RCF damage	Roller hardening	Increased	Unchanged	Unchanged	Unchanged
RAIL - Testing and analysis of welds in CWR; novel materials, technologies, etc. (with Tata) Ultrasonic testing (lab conditions on rail samples) and analysis of results - on welds and Survey of existing	Specifications/ recommendations/ guidelines for novel steels, welding processes, technologies, etc.	Increased	Unchanged	Increased	Unchanged

SKILLS	Innovation	Training	New personnel	Qualifications	Costs
inspection and monitoring technologies (with MerMec).other failure areas.					
RAIL - Impact of profile/inclination on RCF (Romanian profile measurement at/with AFER). Potential work: Ultrasonic testing (lab conditions on various rail samples) and analysis of results. Survey of existing inspection and monitoring technologies (with MerMec).	Specifications/ recommendations for new geometries or combinations (profiles, inclination, etc.), novel steel degradation, etc.	Increased	Unchanged	Increased	Unchanged
RAIL - Wheel profile measurements for track RCF estimation	Dynamic access charges	Increased	Unchanged	Increased	Unchanged
EARTHWORKS - Analysis of multifunctional sensorized geotextiles for subgrade and embankment reinforcement and monitoring	Multifunctional sensorized geotextiles for subgrade and embankment reinforcing and monitoring	Increased	Decreased	Increased	Increased
TRACK - Force information from the WID systems in Sweden and produce statistics on typical load spectra (vertical+lateral) from different trains.	Understanding what the potential is of extending track life by pinpointing and removing bad vehicles from operation.	Increased	Unchanged	Increased	Unchanged
TRACK - Geometry degradation	Optimized maintenance scheduling using novel methods for degradation prediction	Increased	Unchanged	Increased	Unchanged
S&C - Numerical modeling of the vehicle-track dynamic interaction at crossing.	Guidelines on parameters variation on wheel, track geometry, wing/crossing shape and support conditions	Increased	Unchanged	Increased	Unchanged
S&C - Test various lubricants under representative loading conditions	Improved lubrication regime for slide plates under switch rails	Increased	Unchanged	Increased	Unchanged
S&C - Dynamic smart washer - Instrumentation of complex systems (Switches) whilst in operation and with a wide range of dynamic loading –algorithms for railways	Dynamic Smart Washer that allows (through data analysis) adapting condition evaluation of complex system such as switches	Increased	Unchanged	Increased	Unchanged

Further suggestions were provided by Trenitalia Cargo and ERA:

Trenitalia Cargo Maintenance is already provided by high qualified and, in many case, low-paid personnel. A leap forward of the rail industry means an increase of the costs of the maintenance firms.
ERA In some cases, the introduction of new technologies could be strongly opposed by the industry, since it may produce the reduction of

the number of people (or of related time) working on the task influenced by the innovation. But the advantages should be promoted to change this perspective. The introduction of a new technology permits people to acquire new competences, to re-train themselves and to improve their qualifications. In some cases it implies fewer people but more skilful tasks. On the contrary, considering the need of new personnel, the "rail population" is on average old and near to the retirement. New personnel will enter in the sector in the next years and it will be highly qualified, in accordance with the new needs determined by the introduction of the innovations currently under study in Europe.

5.3 Main findings: managerial issues

5.3.1 Maintenance strategy

This paragraph presents the main findings of the questionnaire concerning the effects of the SUSTRAIL innovations on the maintenance strategies of the rail operators.

MAINTENANCE STRATEGY	Frequency	Costs	New Planning
Vehicle			
Optimised Conventional Technology	Decreased (larger intervals) (SIRV) Improved vehicle will reduce frequency of inspection and maintenance(NR) Unchanged(TRE, ERA)	Decreased (larger intervals and less costs) (SIRV) 20-30% reduction in inspection (NR) Unchanged(TRE, ERA)	Need to be aware if new vehicles are introduced on to a route or removed as intervention frequency will need to be adjusted to suit vehicle types in operation. (NR) Unchanged(TRE, ERA, SIRV)
Rail			
Premium Rail Steel	Premium steel offers reduced frequency of inspection and maintenance (50%)(NR) Unchanged (ERA)	Less frequency requires reduced intervention planning resulting in lower cost (circa 50%).(NR) Unchanged (ERA)	Need to identify areas with premium steel to ensure excessive inspection/maintenance avoided. (NR) Unchanged (ERA)

Further suggestions were provided by Trenitalia Cargo and ERA:

Trenitalia Cargo

Maintenance is based on non-technical exigencies. An important issue that has to be resolved in order to increase the efficiency of the maintenance of the rail assets refers to the transit time of wagons from their bases to the workshops.

ERA

Maintenance strategies are based on the exploitation of the assets. Consequently no reduction or increase of the frequency of the maintenance cycles is foreseen through the introduction of the innovations (considering the condition monitoring aspects only) if the exploitation of the assets doesn't change. But I am no expert on this, just my judgment.

5.3.2 Safety

This paragraph presents the main findings of the questionnaire concerning the effects of the SUSTRAIL innovations on the safety of the rail operations.

SAFETY	Global safety	Accidents	Delays	Health conditions	Operational efficiency
Vehicle					
Optimised Conventional Technology	Increased(SIRV) Reduced inspection and maintenance reduces risk to workers by reducing need to go on site(NR) Unchanged(TRE, ERA)	Decreased(SIRV) Reduced inspection and maintenance reduces risk to workers by reducing need to go on site(NR) Unchanged(TRE, ERA)	Decreased(SIRV) Reduced inspection and maintenance reduces the risk of delays of work overrun and associated delays. (NR) Unchanged(TRE, ERA)	Unchanged(SIRV) No change over standard rail(NR) Unchanged(TRE, ERA)	Increased(SIRV) No change over standard rail(NR) Unchanged(TRE, ERA)
Rail					
Premium Rail Steel	positive(Abv) Reduced inspection and maintenance reduces risk to workers by reducing need to go on site(NR) Unchanged (ERA)	positive(Abv) Reduced inspection and maintenance reduces risk to workers by reducing need to go on site(NR) Unchanged (ERA)	positive(Abv) Reduced inspection and maintenance reduces the risk of delays of work overrun and associated delays (5-10%?).(NR) Unchanged (ERA)	positive(Abv) No change over standard rail(NR, ERA)	positive(Abv) No change over standard rail(NR, ERA)

Abv provided a table describing the effects of the entire set of innovations studied in WP4 on the safety of the rail operations.

SAFETY	Innovation	Global safety	Accidents	Delays	Health conditions	Operational efficiency
RAIL - Rolling Contact Fatigue	Improved predictions of RCF damage	positive	positive	positive	positive	positive
RAIL - Rolling contact fatigue – computer modeling for the different times to initiate RCF damage	Roller hardening	positive	positive	positive	positive	positive
RAIL - Testing and analysis of welds in CWR; novel materials, technologies, etc. (with Tata) Ultrasonic testing (lab conditions on rail samples) and analysis of results - on welds and Survey of existing inspection and monitoring technologies (with MerMec).other failure areas.	Specifications/ recommendations/ guidelines for novel steels, welding processes, technologies, etc.	positive	positive	positive	positive	positive
RAIL - Impact of profile/inclination on RCF (Romanian profile	Specifications/ recommendations for new geometries	positive	positive	positive	positive	positive

SAFETY	Innovation	Global safety	Accidents	Delays	Health conditions	Operational efficiency
measurement at/with AFER). Potential work: Ultrasonic testing (lab conditions on various rail samples) and analysis of results. Survey of existing inspection and monitoring technologies (with MerMec).	or combinations (profiles, inclination, etc.), novel steel degradation, etc.					
RAIL - Wheel profile measurements for track RCF estimation	Dynamic access charges	positive	positive	positive	positive	positive
EARTHWORKS - Analysis of multifunctional sensorized geotextiles for subgrade and embankment reinforcement and monitoring	Multifunctional sensorized geotextiles for subgrade and embankment reinforcing and monitoring	positive	positive	positive	positive	positive
TRACK - Force information from the WID systems in Sweden and produce statistics on typical load spectra (vertical+lateral) from different trains.	Understanding what the potential is of extending track life by pinpointing and removing bad vehicles from operation.	positive	positive	positive	positive	positive
TRACK - Geometry degradation	Optimized maintenance scheduling using novel methods for degradation prediction	positive	positive	positive	positive	positive
S&C - Numerical modeling of the vehicle-track dynamic interaction at crossing.	Guidelines on parameters variation on wheel, track geometry, wing/crossing shape and support conditions	positive	positive	positive	positive	positive
S&C - Test various lubricants under representative loading conditions	Improved lubrication regime for slide plates under switch rails	positive	positive	positive	positive	positive
S&C - Dynamic smart washer - Instrumentation of complex systems (Switches) whilst in operation and with a wide range of dynamic loading –algorithms for railways	Dynamic Smart Washer that allows (through data analysis) adapting condition evaluation of complex system such as switches	positive	positive	positive	positive	positive

Further suggestions were provided by Trenitalia Cargo and ERA:

Trenitalia Cargo

Safety refers to the organization of the operations and to the real use of the assets

ERA

It should be emphasized that an important advantage derived from the monitoring of track and vehicles, but particularly track, is that maintenance activities can be planned, reducing the need for changes at short notice. This means that there is time for the safety measures to be put in place and sufficient staff to carry out the work – the maintenance work is safer for the staff – high risk activity. Also remote monitoring of the track will reduce the manual track control activities for the staff and so decrease exposure time, this will also contribute to reducing the risk.

5.3.3 Operations

This paragraph presents the main findings of the questionnaire concerning the effects of the SUSTRAIL innovations on the rail operations in general.

OPERATIONS	Task 1	Task 2	Benefit 1	Benefit 2	New Skill 1	New Skill 2
Vehicle						
Optimised Conventional Technology	Train driving Decreased time(SIRV) Dedicated freight and mixed traffic routes(NR) Unchanged (ERA)	Cross border operations Decreased time(SIRV) Not applicable(NR) Unchanged (ERA)	Decreased time(SIRV) Improved track life and reduced maintenance and inspection(NR) Unchanged (ERA)	Decreased time(SIRV) n/a (NR Unchanged (ERA)	n/a(NR) Unchanged (ERA)	n/a(NR) Unchanged (ERA)
Rail						
Premium Rail Steel	For freight application, it tends to be used for lower speed tighter curves in the range of 0 to 1200m radius. (NR) Unchanged (ERA)	For passenger line application, it is used to counter high bogie stiffness at high speeds and so tends to be used in 700m to 2500m radius curves(NR) Unchanged (ERA)	Improved track life and reduced maintenance and inspection(NR) Unchanged (ERA)	n/a (NR) Unchanged (ERA)	n/a(NR) Unchanged (ERA)	n/a(NR) Unchanged (ERA)

Abv provided a table describing the effects of the entire set of innovations studied in WP4 on the rail operations as a whole.

OPERATIONS	Innovation	Task 1	Task 2	Benefit 1	Benefit 2	New Skill 1	New Skill 2
RAIL - Rolling Contact Fatigue	Improved predictions of RCF damage	no	no				
RAIL - Rolling contact fatigue – computer modeling for the different times to initiate RCF damage	Roller hardening	no	no				

OPERATIONS	Innovation	Task 1	Task 2	Benefit 1	Benefit 2	New Skill 1	New Skill 2
RAIL - Testing and analysis of welds in CWR; novel materials, technologies, etc. (with Tata) Ultrasonic testing (lab conditions on rail samples) and analysis of results - on welds and Survey of existing inspection and monitoring technologies (with MerMec).other failure areas.	Specifications/ recommendations/ guidelines for novel steels, welding processes, technologies, etc.	no	no				
RAIL - Impact of profile/inclination on RCF (Romanian profile measurement at/with AFER). Potential work: Ultrasonic testing (lab conditions on various rail samples) and analysis of results. Survey of existing inspection and monitoring technologies (with MerMec).	Specifications/ recommendations for new geometries or combinations (profiles, inclination, etc.), novel steel degradation, etc.	no	no				
RAIL - Wheel profile measurements for track RCF estimation	Dynamic access charges	no	no				
EARTHWORKS - Analysis of multifunctional sensorized geotextiles for subgrade and embankment reinforcement and monitoring	Multifunctional sensorized geotextiles for subgrade and embankment reinforcing and monitoring	operational links with the dispatchers in motion and/or with ALS systems	operational links with the signaling systems and/or with ALS systems	safety	safety	Exploitation and maintenance the new systems	Exploitation and maintenance the new systems
TRACK - Force information from the WID systems in Sweden and produce statistics on typical load spectra (vertical+lateral) from different trains.	Understanding what the potential is of extending track life by pinpointing and removing bad vehicles from operation.	operational links with the dispatchers in motion and/or with ALS systems	operational links with the signaling systems and/or with ALS systems	safety	safety	Exploitation and maintenance the new systems	Exploitation and maintenance the new systems
TRACK - Geometry degradation	Optimized maintenance scheduling using novel methods for	no	no				

OPERATIONS	Innovation	Task 1	Task 2	Benefit 1	Benefit 2	New Skill 1	New Skill 2
	degradation prediction						
S&C - Numerical modeling of the vehicle-track dynamic interaction at crossing.	Guidelines on parameters variation on wheel, track geometry, wing/crossing shape and support conditions	no	no				
S&C - Test various lubricants under representative loading conditions	Improved lubrication regime for slide plates under switch rails	no	no				
S&C - Dynamic smart washer - Instrumentation of complex systems (Switches) whilst in operation and with a wide range of dynamic loading – algorithms for railways	Dynamic Smart Washer that allows (through data analysis) adapting condition evaluation of complex system such as switches	no	no				

Further suggestions were provided by Trenitalia Cargo:

An improvement in the rail operations will be provided by the division between the technical side of the industry and its commercial scale.

5.3.4 Human interactions, barriers to the implementation and further suggestions

This paragraph presents the effects of the SUSTRAIL innovations on the human interactions as a whole.

(Afer) Risk related to maintenance is lower, simplified the process of maintenance. Additional electronic devices are required and eliminates HF tasks. Lower cost due to larger maintenance intervals. Simplified maintenance processes, productivity increases, safety increases thanks to the monitoring equipment and brake control

(Network Rail) Premium Rail Steel → Reduced inspection and maintenance reduces risk to workers by reducing need to go on site → Reduced inspection and maintenance offsets higher rail cost → No change over standard rail productivity → Optimised Conventional Technology→ Reduced inspection and maintenance reduces risk to workers by reducing need to go on site→ Reduced inspection and maintenance

(Trenitalia CARGO) A substantial improvement of the technologies applied by the industry could produce a reduction in the level of personnel employed in the operations and in the maintenance. This represents a traditional barrier to the innovations in the rail sector.

(ERA) It should be emphasized that an important advantage derived from the monitoring of track and vehicles, but particularly track, is that maintenance activities can be planned, reducing the need for changes at short notice. This means that there is time for the safety measures to be put in place and sufficient staff to carry out the work – the maintenance work is be safer for the staff – high risk activity.

It is important to underline that barriers derive from the way an innovation is presented. If technicians involve people in design, if the approach is centered on the persons than no barrier will be created against something that improves the efficiency and the quality of the output produced by an industry.

Other barriers to the implementation of the innovations:

(Network Rail) Premium Rail Steel is proving to offer a worthwhile reduction in inspection and maintenance, with increase life. Apart from a higher initial purchase price for the rail, there are no barriers to implementation over conventional rail and the break-even point occurs relatively early on (approximately 2 years according to application) to provide a good business case for implementation. The introduction of the optimised vehicle will further increase track life, but incentives will need to be introduced to encourage their implementation, probably in the form of reduced track access charges.
(Trenitalia CARGO) The rail industry is stiff and in many cases non competitive due to its own nature. This represents a barrier to the introduction of technological innovations. And this marks the difference between the road transport, that is a competitive market. This is true also considering also the maintenance activities and the competition within the maintenance sector. Moreover, technically speaking, another barrier to the maintenance, to the safety and to the efficiency of the system is represented by the structure of the wagon that is very complex. In this field the BTZ experience is recalled.
(ERA) It should be emphasized that an important advantage derived from the monitoring of track and vehicles, but particularly track, is that maintenance activities can be planned, reducing the need for changes at short notice. This means that there is time for the safety measures to be put in place and sufficient staff to carry out the work – the maintenance work is be safer for the staff – high risk activity.

Finally, ERA provided further suggestions for future research in this domain

(ERA) The most important idea is that innovations have to be based on a "human- centered approach". This is a theory [principle that wants to move influence the focus of the technicians on the human factor issues inside the projects and support the involvement of HF experts in the design and development teams. This approach could permit the introduction of new technologies, the improvement of the efficiency of the system and the reduction of the conflict in some areas.

5.4 Results

The following images summarize the main results of the questionnaire for the optimised conventional technology and for the premium rail steel. It has to be underlined that results are adjusted in order to show the main output of the questionnaire. In case of absence of univocal outputs it was chosen the main result in terms of majority of selections[8].

[8] The following shceme shows the methodology that was applied to reach such results. **Vehicle.** Question 5.2.2 Inspectability - Safety. No effects 4 (TR, ERA, NR, SIRV) | Positive effects 0 | Negative Effects 0. The final result is unchanged. **Premium Rail Steel**. Question 5.3.2 Safety- Global Safety. No effects (ERA) | Positive effects (ABV, NR) | Negative Effects 0. The final result is increased.

Maintenability	Frequency	Automation	Costs		
	Decreased	Increased	Decreased		
	3	2	3		
Inspectability	Safety	Efficiency	Costs	Frequency	Time
	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged
	4	3	2	2	3
Accessibility	Efficiency	Costs			
	Unchanged	Unchanged			
	4	4			
Ergonomic	Working position	Dangerous Location			
	Unchanged	Unchanged			
	4	4			
Handling of maintenance tools	New Tools	New Machinery			
	Unchanged	Unchanged			
	2	3			
Skills	Training	New Personnel	Qualifications	Costs	
	Unchanged	Unchanged	Increased	Unchanged	
	2	2	2	2	
Maintenance strategy	Frequency	Costs	New Planing		
	Unchanged	Unchanged	Unchanged		
	2	2	4		
Safety	Global safety	Accidents	Delays	Health conditions	Operational efficiency
	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged
	2	2	2	4	4

Figure 4 Optimised conventional technology-intensity of the results

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

Figure 5 Optimised conventional technology-main results

Maintenability	**Frequency**	**Automation**	**Costs**		
	Decreased	Unchanged	Decreased		
	3	1	2		
Inspectability	**Safety**	**Efficiency**	**Costs**	**Frequency**	**Time**
	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged
	2	2	2	2	3
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**	**Operational efficiency**
	Increased	Decreased	Decreased	Unchanged	Unchanged
	2	2	2	2	2

Figure 6 Premium Rail Steel -intensity of the results

Maintenability	**Frequency**	**Automation**	**Costs**		
	Decreased	Unchanged	Decreased		
Inspectability	**Safety**	**Efficiency**	**Costs**	**Frequency**	**Time**
	Unchanged	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**	**Operational efficiency**
	Increased	Decreased	Decreased	Unchanged	Unchanged

Figure 7 Premium Rail Steel-main results

6. CONCLUSIONS

The outcome of the interviews gives useful provisional insights on the impacts of SUSTRAIL innovations on human factors. In particular, the stakeholders interviewed agreed that the effort in maintenance and inspections will decrease, however, they are not able to quantify or to assess homogeneously the magnitude. This is due to the difficulties that many of the interviewer have find in identifying the scope of the SUSTRAIL innovations.

The results of the interviews reflect the expectation in a decrease in track and vehicle maintenance efforts. In fact, this area is expected to benefit most from SUSTRAIL innovations 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 of 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 skill sets required – such as an increase in engineer and technical skills and skills to work with computer and digital systems – and hence it necessitates training activities to accompany the introduction of SUSTRAIL innovations.

One major objective of the interviews was also to identify barriers for introducing SUSTRAIL innovations. The experts were able to provide some useful insights on this regard, such as the concern of the rigidity of the industry.

7. REFERENCES

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