PROJECT FINAL REPORT

Grant Agreement number: 285162

Project acronym: D-RAIL

Project title: **Development of the Future Rail Freight System to Reduce the Occurrences and Impact of Derailment**

Funding Scheme: **FP7 THEME [SST.2011.4.1-3.] [Reducing the occurrences and impacts of freight train derailments]**

Period covered: from **01/ 10/ 2011** to **30/ 09/ 2014**

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[1] Usually the contact person of the coordinator as specified in Art. 8.1. of the Grant Agreement.

[2] The home page of the website should contain the generic European flag and the FP7 logo which are available in electronic format at the Europa website (logo of the European flag: http://europa.eu/abc/symbols/emblem/index_en.htm logo of the 7th FP: http://ec.europa.eu/research/fp7/index_en.cfm?pg=logos). The area of activity of the project should also be mentioned.

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4.1 Final publishable summary report

Executive Summary

In 2009, the European Railway Agency (ERA) identified that substantial benefits for quality of service and safety of railway freight transport may be achieved by a significant reduction of freight train derailments. From the sector's economic perspective it was estimated that the open line freight train derailments in EU 27 cost more than 200 million Euros per year, and were almost entirely related to infrastructure and rolling-stock damages as well as operation disruption impacts (ERA/REP/03-2009/SAF).

Causes of derailments should be investigated in parallel (e.g., condition of the infrastructure, condition of the rolling stock, human error); therefore, the research is to analyse existing knowledge on derailments mechanisms and complement it, in particular in regards combined causal effects.

The direction of the D-RAIL project is threefold, involving multiple and diverse objectives included the following main goals:

- *Prevention:* To reduce derailment impacts to balance the mechanical effect of railway traffic increase on accident numbers.

- *Mitigation:* Develop, from causal analysis, suitable monitoring/inspection systems to reduce the propensity for freight derailment.

- *Standards:* Develop, through evaluation and testing, suitable guidelines and outline standards for detecting and prevention of derailments.

D-RAIL employed a complex architecture and a comprehensive and competent consortium, including twenty partners from across Europe, with a wide geographical representation. Partners included Infrastructure Managers, Operators, Industry and Academia. D-RAIL was a Global project, involving International support, such as the International Railways (UIC), Russia (RZD) and USA (partner HARSCO).

The work in the D-RAIL project was organised in nine Work Packages, as follows:

- Seven technical Work Packages (WP1 – WP7);

- Dissemination and exploitation Work Package (WP8), and

- Management and coordination Work Package (WP9).

The D-RAIL project has now completed all the key elements in identifying and analysing the derailment causes and impacts **(WP1)** for future research work and testing within the project. An in-depth analysis of derailment databases has been completed, allowing for the definition of particular causes and effects, with regard to infrastructure, rolling stock and operational aspects.

Focussing on freight trends to 2050, **WP2** has identified the trends of rolling stock up to 2050, with particular regard to freight wagon types and technology development capable of influencing the occurrence of derailments. A comprehensive cost/benefit analysis was also carried out to demonstrate the economic impact of implementing various supervision and mitigation measures; these were identified and discussed within WP4.

WP3 has finalised a detailed technical analysis of derailments with respect to causes, impacts and possible prevention measures. It has identified and evaluated, through simulation and analysis, the key contributory factors associated with derailment including combined causal effects for the freight vehicle and track system. The study has provided cost effective solutions to reduce or

eliminate the propensity for derailment and provide improved levels of safety, which were further considered by WP4, 5 and 7.

The Work Package **WP4** has finalised with a critical assessment of current and emerging inspection and monitoring techniques related to derailment prevention and mitigation purposes, in relation with the in-depth survey and analysis which were carried out and completed in the first reporting period. The study had to cover wayside and vehicle based technologies, and dedicated recording wagons. From the assessment, WP4 partners were capable to establish the improvements and/or new required features to improve derailment prevention.

WP5 has been completed with business cases developed which considered the identified boundary conditions. Data exchange issues were analysed with respect to data types, data interpretation, protocols, compatibility between systems, etc., in the context of different strategies for the implementation and exploitation of the current systems which were also discussed.

WP6 has been successfully completed with the testing of selected monitoring concepts on test sites, alongside the testing of the effectiveness of derailment detection systems in cross border operations. Two test locations were instrumented for both track and freight vehicles and novel technologies were evaluated to determine the step changes in safety performance required for derailment prevention.

WP7 has achieved its objectives and demonstrated the feasibility of the D-RAIL project targets (reduce the occurrence of freight train derailments within Europe by between 8-12% and derailment related cost reductions by 10-20%) by performing technical and economical assessments through RAMS and LCC analyses.

WP8 developed and launched the project website in the first months of the project. The initial website was further updated and new sections were added to host relevant information and results.

D-RAIL partners have also carried out an intensive dissemination of the overall project and its results in a series of significant European and International events. Moreover, outreach and marketing of the research findings were presented throughout the project to a wide variety of stakeholders, regulatory bodies and end users to ensure industry awareness.

4.1.1   Project context and objectives

In 2009, the European Railway Agency (ERA) identified that substantial benefits for quality of service and safety of railway freight transport may be achieved by a significant reduction of freight train derailments. It is also considered that small or fragmented improvements of existing safety measures might be neither significant nor sustainable in regards of the foreseeable evolution of railway freight transport, as described in 'A sustainable future for transport' [COM(2009) 279/4], and the expected increase of railway traffic.

Any intervention on the transport sector must be based on a long-term vision for the sustainable mobility of people and goods, not least because policies of structural character take longer to implement and must be planned well in advance. Society is likely to demand greater transport safety, security and comfort, therefore an improvement of the overall quality of transport, including personal security, the reduction of accidents and of health hazards must remain a high priority within transport policy. Working conditions must also be improved for transport workers, particularly with regard to health and safety risks. Concerning freight transport, an intelligent and integrated logistics system must become reality, infrastructure should be well maintained and improvement works coordinated. This will reduce accidents and operating costs as well as congestion, pollution and noise.

New infrastructure is costly, and making optimal use of existing facilities will, in itself, achieve much, given more limited resources. This requires proper management, maintenance, upgrading and repair of the large infrastructure network that has, so far, given Europe a competitive advantage. Upgrading the existing infrastructure - also through intelligent transport systems - is in many cases the cheapest way to enhance the overall performance of the transport system. To introduce promising technologies to commercial markets, policy makers must introduce the necessary framework conditions, without giving undue advantage to any specific technology. New transport systems and vehicle technologies will first have to be implemented as demonstration projects, so as to assess their feasibility and economic viability.

To ensure a consistent EU legislation, the ERA was requested to examine and make recommendations to the Commission about a new proposition made by the RID Committee of Experts requiring the use of Derailment Detection Devices (DDD) as from the 1st January 2011 for specific categories of Dangerous Goods wagons. The Agency has recommended to the Commission that this new provision should not be adopted. Impact assessment suggests that cost-effective risk reduction might potentially be achieved with preventative measures, beneficial for all freight train derailments, instead of trying to mitigate a few derailments of specific dangerous goods wagons.

There is no existing EN standard defining the functionalities and the required performances for derailment detection devices. A concern was that imposing such devices now may thus give undue competitive advantages to the few suppliers of DDD existing today. Article 4 of the EU Railway Safety Directive 2004/49 gives a clear preference for accident prevention measures. The problem is significant - 691 freight train derailments have occurred within the EU over the last 10 years. From the sector's economic perspective it was estimated that the open line freight train derailments in EU 27 cost more than 200 million Euros per year, and were almost entirely related to infrastructure and rolling-stock damages as well as operation disruption impacts (ERA/REP/03-2009/SAF).

The causes of derailments should be investigated in parallel (e.g. condition of the infrastructure, condition of the rolling stock, human error); to this end, the research is to analyse existing knowledge on derailments mechanisms and complement it, in particular in regards combined causal effects. The report of the 10th meeting OTIF/RID/CE/GT/2009-A stated *"It was incomprehensible why fully developed technology could not be employed throughout Europe, even though it could already be demonstrated that this technology can reduce the extent of accidents"*

(Cornaux/Switzerland).

Therefore, the direction of the D-RAIL project is threefold, involving multiple and diverse objectives, as shown in below **Table 1**

Table 1 Threefold objectives of D-RAIL project

Prevention	Mitigation	Standards
To reduce derailment impacts to balance the mechanical effect of railway traffic increase on accident numbers.	Develop, from causal analysis, suitable monitoring/inspection systems to reduce the propensity for freight derailment.	Develop, through evaluation and testing, suitable guidelines and outline standards for detecting and prevention of derailments.
➢ *Understand the causes of derailment from accident statistics* ➢ *Determine the economic and social impact of freight derailment* ➢ *Improve the competitiveness of freight in comparison to other transport modes* ➢ *Reduce the impact of freight derailment on other rail users and operation*	➢ *Understand the failure mechanisms and develop a means to detect* ➢ *Identify existing and new technology for its suitability to detect derailment causes* ➢ *Integrate technology to monitor both wayside and vehicle conditions* ➢ *Develop new concepts which can be cost effectively deployed*	➢ *Provide an understanding of the RAMS and LCC of derailment detection* ➢ *Produce guidelines for adoption of monitoring systems across Europe* ➢ *Develop functional requirements and standards for industry use* ➢ *Improve cross border operation of freight towards the 2050 vision*

In order to achieve these ambitious goals, the D-RAIL project employed a complex architecture, structured in 8 work packages *(Figure 1)*, and a comprehensive and competent consortium. *Figure 1* shows how a good coordination between WPs was a key factor for success of D-RAIL.
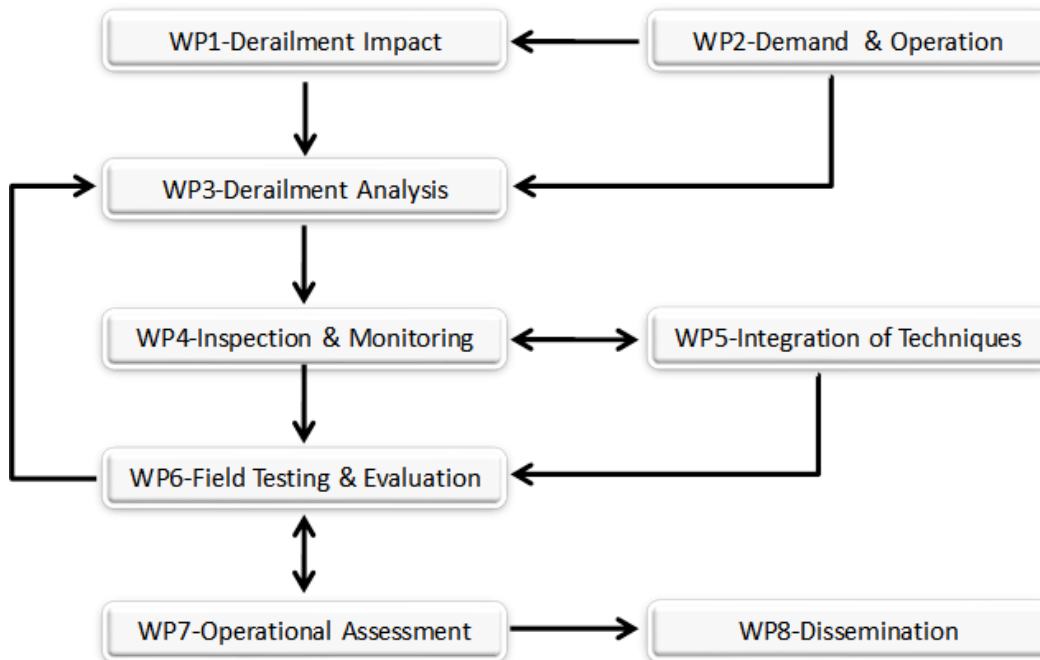
*Figure 1 D-RAIL project architecture*

D-RAIL project consortium:
➢ Twenty partners from across Europe with a wide geographical representation
➢ Partners include Infrastructure Managers, Operators, Industry and Academia

> ➤ Global project which includes International Railways (UIC), Russia (RZD) and USA (Harsco)
>
> ➤ Many partners have significant International rail experience outside the EU.

The overall structure determined by the work flow and consortium is illustrated in ***Figure 2*** below.
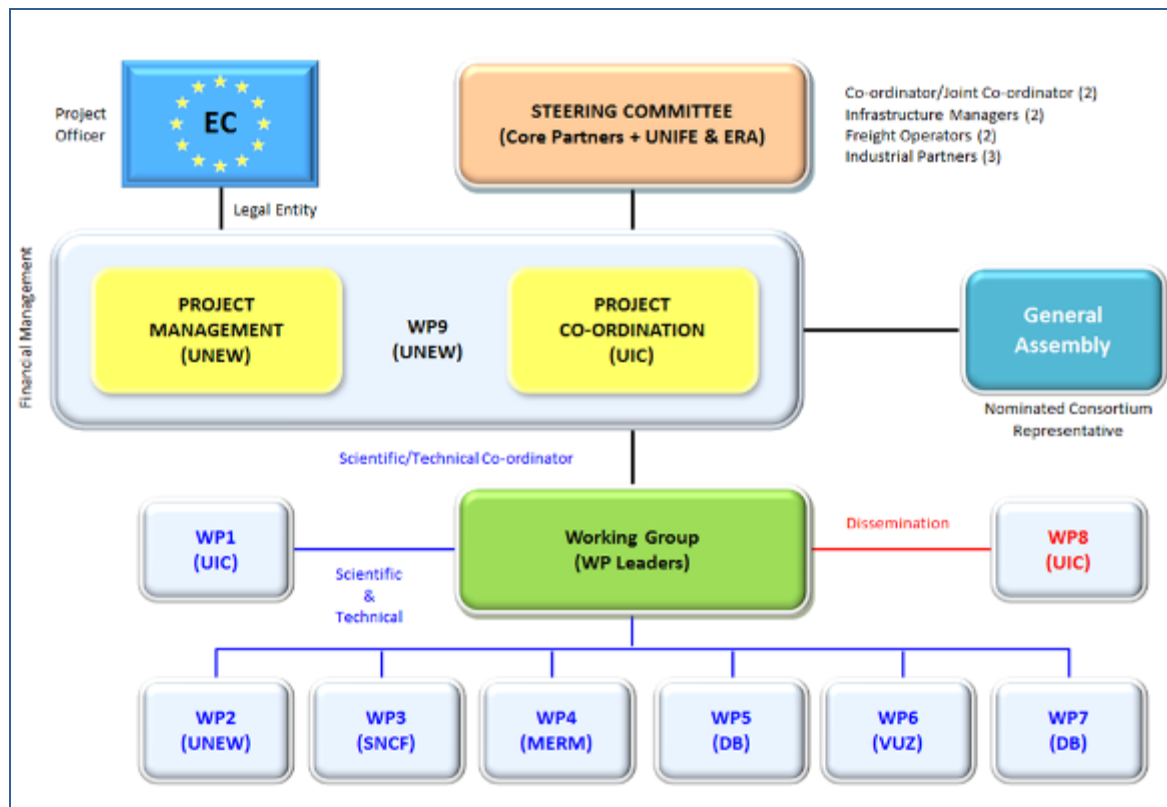
Figure 2 D-RAIL project structure

4.1.2   *Main S&T results/foregrounds*

The work in D-RAIL project was organised in work packages, which were described in detail and scheduled in the Annex I to the Grant Agreement. The Work Packages' schedules are shown in the project's Gantt diagram (***Figure 3***).

The D-RAIL project has now completed all the key elements in identifying and analysing the derailment causes and impacts (WP1) for future research work and testing within the project. An in-depth analysis of derailment databases has been completed, allowing for the definition of particular causes and effects, with regard to infrastructure, rolling stock and operational aspects.

Focussing on freight trends to 2050, WP2 has identified the trends of rolling stock up to 2050, with particular regard to freight wagon types and technology development capable of influencing the occurrence of derailments. A comprehensive cost/benefit analysis was also carried out to demonstrate the economic impact of implementing various supervision and mitigation measures; these were identified and discussed within WP4.

WP3 has finalised a detailed technical analysis of derailments with respect to causes, impacts and possible prevention measures. The study was concluded within three deliverables, which were sent to experts for review and comments. This work package has identified and evaluated, through simulation and analysis, the key contributory factors associated with derailment including combined

causal effects for the freight vehicle and track system. The study has provided cost effective solutions to reduce or eliminate the propensity for derailment and provide improved levels of safety, which were further considered by WP4, 5 and 7.

No.	WP/Task Description	Year 1												Year 2												Year 3											
		2011			2012									2012/13			2013									2013/14			2014									
		O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
WP01	DERAILMENT IMPACT																																				
1.1	Accident data collection																																				
1.2	Causal Analysis																																				
1.3	Derailment Impact																																				
1.4	Market Uptake																																				
WP02	FREIGHT DEMAND & OPERATION																																				
2.1	Synthesis of freight forecast (2050)																																				
2.2	Rolling stock breakdown (2050)																																				
2.3	Cost/benefit analysis																																				
WP03	DERAILMENT ANALYSIS																																				
3.1.	Analysis of derailment causes																																				
3.2	Analysis & mitigation (wheel/rail)																																				
3.3	Analysis & mitigation (fatigue/fracture)																																				
WP04	INSPECTION & MONITORING																																				
4.1	Survey of existing systems																																				
4.2	Assessment of existing systems																																				
4.3	Improvement of existing systems																																				
WP05	INTEGRATION OF MONITORING																																				
5.1	Development & integration of concepts																																				
5.2	Classification & migration of concepts																																				
WP06	FIELD TESTING & EVALUATION																																				
6.1	Testing to support numerical simulations																																				
6.2	Pilot technology testing																																				
6.3	Field testing of integrated system																																				
6.4	Cross border testing																																				
6.5	Test evaluation																																				
WP07	OPERATIONAL ASSESSMENT																																				
7.1	Methods for analysis																																				
7.2	RAMS/LCC management & boundaries																																				
7.3	RAMS analysis																																				
7.4	LCC analysis																																				
7.5	Recomendations & findings																																				

Figure 3 D-RAIL *project programme*

The Work Package WP4 has finalised with a critical assessment of current and emerging inspection and monitoring techniques related to derailment prevention and mitigation purposes, in relation with the in-depth survey and analysis which were carried out and completed in the first reporting period. The study had to cover wayside and vehicle based technologies, and dedicated recording wagons. From the assessment, WP4 partners were capable to establish the improvements and/or new required features to improve derailment prevention.

WP5 has been completed with business cases developed which considered the identified boundary conditions. Data exchange issues were analysed with respect to data types, data interpretation, protocols, compatibility between systems, etc., in the context of different strategies for the implementation and exploitation of the current systems which were also discussed.

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WP7 has achieved its objectives and demonstrated the feasibility of D-RAIL project targets (reduce the occurrence of freight train derailments within Europe by between 8-12% and derailment related cost reductions by 10-20%) by performing technical and economical assessments through RAMS and LCC analyses.

The section below presents more details on the progress towards objectives and details for each task, highlighting the most significant results, and explaining deviations from Annex I if/where it is the case.

WP1 Derailment impact

The objective of WP1 was to provide a comprehensive review of existing freight derailments including the combined causal effects to evaluate the root causes and severity of impacts.

Existing derailment data were used as the benchmark position and analysed to provide valuable information on the root causes of freight derailments and subsequent severity of impacts. As part of the initial benchmarking, the work previously undertaken by the European Rail Agency (ERA/2010/SAF/OP/01) which examines some of the existing technical and operational measures has also been included. Current monitoring technologies and techniques in relation to both freight vehicles and infrastructure (wayside) were considered to determine what causal effects are currently being monitored, and the effectiveness of these technologies in relation to freight operation and safety. The impact of derailment on railway operation has been assessed to understand the financial implications of damage to vehicles/infrastructure, disruption and delays.

Details of tasks associated with work package 1 and their status are given in ***Table 2*** below.

Table 2 WP1: Task Status Breakdown

Task no.	Task description	Comments and summary of results
1.1	**Derailment Accident Data Collection |** Collection of derailment accident data to ensure adequate benchmarking.	All data collection for the tasks 1.1 - 1.4 was done together. Data were gathered in Excel database format. Issues: Data about derailments belong to a variety of organisations and are presented in various formats differing in structure, information under which criteria is reported and the definition of causes of accidents, etc. Some are public and some are not. There is urgent need to unify and simplify railway accident reporting in Europe.
1.2	**Freight Vehicle(s) |** Collection of specific freight vehicles derailment data, based upon the requirements of WP3.	
1.3	**Infrastructure |** Collection of specific track and infrastructure derailment data, based upon the requirements of WP3.	
1.4	**Operation |** Collection of specific freight operation where derailments have occurred, based upon the requirements of WP3.	
1.5	**Causal Analysis |** Assessment of the reported root causes of freight derailments, based upon the requirements of WP3.	For causal analysis, only a selection of derailments was used, with focus on the main causes which were captured. Outcomes of Tasks 1.1 – 1.5 are included in Deliverable D1.1 and its 2 Annexes. Annex 2 is the D-RAIL database.
1.6	**Derailment Impact |** Details of the impact of freight derailments will, where available, be provided including an assessment of the economic impact.	Cost data are especially difficult to obtain as well as the permission to use them. A new model for calculation of accident impact was developed and proposed. Results of Task 1.6 and 1.7 are presented in Deliverable D1.2.
1.7	**Market Uptake |** How to ensure that the proposed derailment detection and mitigation measures are affordable and could be practically adopted by relevant stakeholders.	

D1.1: Summary report of database of derailments incidents

Tasks 1.1-1.4 have gathered information on numbers of derailments and their causes from countries in Europe and around the world, and associated costs where available. The objective was to identify

the major causes of derailment as a starting point for the detailed analysis of derailment causes in WP3.

The review of project partner countries' mainline freight train derailments focuses on the six-year period 2005-2010. The statistics collected here for this period show that the number of derailments occurring each year is in general declining. Derailment data were collected from safety databases in the USA, Russia, and several European countries, as well as UIC and ERADIS, and brought together into a single database. Derailment causes have been categorised using a variant of the system used in the recent study for ERA by DNV. Causes have been ranked according to the proportion of derailments occurring within each category, and this has provided the following ranking of *derailment causes in Europe:*

1. *Axle ruptures*
2. *Excessive track width*
3. *Wheel failure*
4. *Skew loading*
5. *Excessive track twist*
6. *Track height/cant failure*
7. *Rail failures*
8. *Spring & suspension failure*

Derailment causes data and statistics in Europe were assessed and compared against similar worldwide information, which was made available through D-RAIL partners (UIC and HARSCO). Derailment causes were similarly identified and ranked in the USA and in the world. Differences between Europe, the USA and world level were analysed and explained.

It was found that infrastructure and rolling stock are responsible for most derailments on open line and in stations, while operations are the dominant cause in shunting yards. Countries differ in their infrastructure, rolling stock and operation parameters, which can create wide variation in the key derailment causes.

Although regulations covering reporting of accidents are now in place in the European Union, there is still significant variation in the quality of reporting across the Member States. Detailed information on derailments, their causes and costs, is often available only from private databases in each country. Costs, in particular, are very difficult to estimate, as different financial procedures are implemented in different countries, and the impact of derailments can often be over several years.

In addition to the report, deliverable D1.1 comprises a very comprehensive database of derailments across Europe and across the world. All information gathered during the research in tasks 1.1 – 1.4 was synthesised and aligned into the *D-RAIL derailment database*, including relevant data on derailments from the last 10 years (such as location, date, causes, impacts, etc.) The main sources contributing to this valuable database were the DNV and UIC databases, the ERADIS and national accident databases from Austria, UK, USA, etc. An example of the D-RAIL database can be found in the appendices of the report, but it is also publicly available as an Excel spreadsheet.

Initial findings were presented to the ERRAC Evaluation Working Group (Milestone MS01), which provided recommendations to be considered by the project as in continued (details in section 3.3 and *Appendix 1*). The recommendations were very useful and ensured the consideration of the implementation of the D-RAIL results.

D1.2: Report on derailment economic impact assessment

This report provides details on the impact of freight derailments, including an assessment of the economic impact. Data sources were European databases EUROSTAT and ERADIS, information from project partners' databases and information from previous reports, studies and papers.

From the analysis of derailment impact in this deliverable, a number of observations can be made for modelling derailment costs:

- o There are 500 derailments per year, of which 7% (35 derailments) involve dangerous goods.

- o There are, on average, 2 fatalities per year and 3 serious injuries per year, at costs of 1.5M€ per fatality and 0.2M€ per serious injury, so the human cost is 3.6M€ per year. This is equivalent to a human cost of 7200 € per derailment.

- o Environmental clean-up costs are negligible except in the 7% of derailments involving dangerous goods. If the minimum cost per dangerous goods derailment (250000 €) is assumed here, this is equivalent to 17500 € per derailment.

Based on this, the human and environmental costs add a fixed cost of 24700 € per derailment, regardless of the type of derailment. However, this is an average value, and could be thought of as, for example, six severe derailments per year, each incurring costs of 2M€ (rather than 500 derailments per year, each incurring the cost of 24700 € per derailment).

In data collection, the costs were split into two major groups:

- o Direct costs, meaning just the railway asset costs of infrastructure and rolling stock that are damaged during or after a derailment.

- o Indirect costs, including e.g., disruption cost (delay minutes, etc.), fatalities and injuries costs, legal and litigation costs, third party damage, environmental (this could include post-accident clean-up operation, etc.), attendance of emergency services, public dangers (hazardous cargo), loss of cargo and freight.

The data collected in D-RAIL indicates an 80%/20% split of direct costs between infrastructure and rolling stock.

In addition to the analysis focusing on European data and methodology, the report also contains a section dedicated to the study of impact assessment of derailments in the USA. The section includes a sub-section focusing on the distribution of derailment costs in the USA, which is further exemplified by relevant case studies.

For calculating the total impact in cases where only direct costs are known, the direct cost should be multiplied by a factor – ERA's cost benefit analysis model gives a factor of 2.5. Data for the USA indicate this factor is known to be 1.8 - 2. The analysis of the data provided by infrastructure managers in the D-RAIL project suggests that this factor may be much lower (only 1.33) but it is likely that this varies considerably between countries.

WP2: Freight Demand & Operation

This work package was to evaluate trends for the railway freight system of the future towards the freight target system of 2050. This has to embrace future European rail policy and strategy for freight and the likely impact on future operation and technologies. Future trends for the movement and loading of freight, logistics and sector economic aspects were assessed as part of the review to support future derailment scenarios based on the impact analysis from WP1, and to ensure that the

approach embraces the future freight vision. Freight vehicles and fleet operation, including loading aspects, will also be examined for existing and future requirements. A future oriented analysis of costs and benefits of reducing, or even mitigating, derailments or reducing impacts is only possible if it is known how the future rail freight market (commodities, types of wagons, operational patterns, etc.) will develop; this is the context of this Work Package. The importance of WP2 increased after obtaining access to the ERA reports produced by Det Norske Veritas (DNV), as detailed below.

Table 3 WP2: Task Status Breakdown

Task no.	Task description	Comments and summary of results
2.1	**Synthesis of Freight Forecast to 2050 |** Ongoing and recently completed EU research for the freight system integrated into D-RAIL approach.	Three freight demand scenarios were developed within D2.1. The implications for the rail freight sector in terms of wagon fleet capacity and capability are significant, as is the availability of infrastructure to accommodate the much higher demands expected.
2.2	**Rolling Stock Breakdown to 2050 of Rail Freight Forecast |** Analysis and then broken down into specific rolling stock types and models, operational conditions mapped by transport corridors, regions and different rail infrastructures.	The study, which completed with deliverable D2.2, concludes that Open top wagons, Flat wagons, Covered wagons and Covered hopper wagon will feature most prominently in the rail freight rolling stock fleet in EU27 in 2050.
2.3	**Cost/Benefit Analysis |** Economic analysis of derailment using costing tools, to obtain the relative benefit/disbenefit of adopting differing interventions to reduce freight derailment.	The monetisation of the derailment accidents and the evaluation of the intervention techniques are performed combining two approaches. The Cost and Benefits Analysis (CBA) to 2050 was based on eight sets of interventions which target the top eight derailment causes.

D2.1: Report on rail freight forecast to 2050

WP2 has initially reviewed and considered valuable results of previous EU funded projects focusing on the forecast of freight demand and rolling stock trends. The overview of past and ongoing studies under the task 2.1 involved literature reviews of all projects listed in Annex I and supplemented by projects outside the list. Based on the availability of published online material and their relevance to D-RAIL, the projects were grouped into three categories:

- Projects relevant to D-RAIL, i.e., those including information with regard to both rail freight forecasting and future rolling stock breakdown (e.g., NEWOPERA, CREAM, MARATHON, RETRACK, SPECTRUM, etc.);

- Projects partly relevant to D-RAIL, i.e., those providing information on either forecasting or freight forecasting and future rolling stock breakdown (e.g., TRANSVISIONS, TEN-CONNECT, FREIGHTVISIONS), and,

- Projects not relevant to D-RAIL, i.e., those which contained no information directly or indirectly related to forecasting or rail freight forecasting and future rolling stock breakdown.

Three scenarios were developed: the Reference scenario, where no major policy change occurs in the future and two White Paper scenarios which assume that there will be a significant shift in freight demand from road to rail in the period to 2050. In terms of tonnes (lifted), total freight

demand is expected to grow on average by 1.53% annually according to the Reference scenario. This average growth rate increases significantly in the White Paper High Scenario, strongly affecting the modal split and doubling rail freight demand. In the White Paper Low scenario, total demand is increased by almost 20% over the present position (that is compared to Reference scenario in 2050) while in the White Paper High scenario, the total demand is expected to almost double, favouring long-distance transport. The implications for the rail freight sector in terms of wagon fleet capacity and capability are therefore significant, as is availability of infrastructure (e.g. line capacity and train paths) to accommodate the much higher demands expected.

D2.2: Future rolling stock breakdown to 2050

The study concludes that Open top wagons, Flat wagons (for containers), Covered wagons and Covered hopper wagons will feature most prominently in the rail freight rolling stock fleet in EU27 in 2050.

On the basis of the corridor (origin destination country pairs) analysis, the study concludes that Flat wagons or Covered wagons will be important for the NL-DE, DE-IT, DE-NL, BE-FR, and FR-BE corridors for the transport of Crude manufacturing, building materials; Open top wagon for PL-DE, CZ-DE, and CZ-DE corridors for transport of solid mineral fuels; Covered hopper wagons for DE-AT corridor for transport of agriculture products; and Covered hopper wagons for the SK-CZ corridor for the transport of Fertilisers.

D2.3: Cost/benefit analysis for intervention

The monetisation of the derailment accidents and the evaluation of the intervention techniques are performed combining two approaches. The first approach assumes two scenarios: constant derailments scenario; where the annual number of derailments is assumed at 500 (unchanged); and decreasing (10% to 20%) derailments scenario throughout the analysis period. The second approach uses the Cost and Benefits Analysis (CBA), a quantitative tool used by decision makers to determine, in this case with a set of intervention techniques, a project's cost appropriateness, efficiency and effectiveness. This approach, hence, produces the costs and benefits, up to 2050, based on eight sets of interventions which target the eight derailment causes.

All WP2 results were presented in detail at a validation workshop (Milestone MS02) organised at UIC in Paris (more details in section 3.3). Experts from relevant UIC working groups and industry were invited, and the workshop was a successful event which provided the validation feedback, as well as the final input in WP2 deliverables.

The work performed in WP1 and WP2 has benefitted of a significant source of information and input, respectively the DNV study and the ERA report based on the analysis and conclusions on DNV study. However, the partners of D-RAIL project made serious efforts to complement these studies and go beyond their results. Considering the results achieved by WP1 and WP2, delivered in substantial reports and a comprehensive database, it can be remarked that D-RAIL project has achieved these objectives.

The main *achievements of WP1 and WP2, in comparison with the previous studies*, include:

➢ A more technical and scientific perspective on derailment causes and impacts; causality was investigated and breakdown at a very detailed level, and consequent impacts were similarly addressed;

➢ A much wider geographic dimension, including relevant non-EU countries, such as Russia and the USA;

> Collection and use of data from other direct sources (national, such as Austria, Germany, GB, etc., and European, from UIC);

> A deep and detailed analysis of the information in the database, which has resulted in relevant statistics and conclusions;

> A new economic approach (top-down, from goals to possible measures, on a European level), which offered a new perspective on the assessment of reducing the derailment impacts.

WP3: Derailment Analysis

This work package was to identify and evaluate, through simulation and analysis, the key contributory factors associated with derailment including combined causal effects for the freight vehicle and track system. The study has evaluated these factors to provide cost effective solutions to reduce or eliminate the propensity for derailment and provide improved levels of safety. Reductions in derailments have to be quantified in relation to current incidents and consequences and will demonstrate a step change in prevention. Derailment scenarios have been assessed based upon existing benchmark analysis to determine the extent of causal effects to support future improvements. A number of derailment mechanisms and influencing factors have been evaluated, undertaken for both vehicle and track based, on an understanding of the 'total' integrated freight system.

Table 4 WP3: Task Status Breakdown

Task no.	Task description	Comments and summary of results
3.1	**Analysis of Derailment Causes, Impact and Prevention Assessment Schemes |** To provide valuable information on the root causes of freight derailments and subsequent severity.	Overview of the major derailment causes identified and listed in the Deliverable D1.1. The results were structured to identify all mitigation measures for the given major derailment causes in a systematic way. The potential for new measures was identified. These results provide an input for WP 4 to analyse the listed mitigation measures in more detail. The focus of all measures is primarily technology-oriented to gain advantages from automated inspection.
3.2	**Analysis & Mitigation of Derailment Related to Wheel/Rail Interaction |** Initial focus in the areas of flange climbing (operational aspects) and switches and crossings with respect to the derailment impact analysis (WP1); modifying the approach as the findings of this research emerge.	This task concerned derailment due to rail climbing on line and in switches and crossings, and also due to material failure. These studies incorporate all of the main derailment mechanisms identified in WP1, with the exception of axle failures that are dealt with e.g. in EURAXLES and explicitly excluded in Annex I. Additional parts were added to form a full report (Deliverable D3.2). In parallel, D3.3 is, to a large extent, a compilation of the main results of deliverable D3.2. The WP supported the incorporation of the WP results in subsequent WPs and to the society.
3.3	**Analysis & Mitigation of Derailment Due to Material Fatigue & Fracture |** Initial focus in the areas of wheel failures, rail breaks and axle failures with respect to the derailment impact analysis (WP1); modifying the approach as the findings of this research emerge.	

WP3 has finalised 3 deliverables. The deliverable D3.2 was also sent for review and comments to the UIC-Track Expert Group (TEG) and to leaders of WP4, 5, 6 and 7. The deliverables D3.3 and D3.2 were subsequently updated according to the feedback during the review of D3.2, in order to obtain a compact and useful compilation of main conclusions and recommendations.

D3.1: Analysis of derailment causes, impact and prevention

The report gives an overview of the findings of several workshops on the investigation of the major derailment causes identified and listed in the Deliverable D1.1. The results of the workshops were put into an overall structure to identify all mitigation measures for the given major derailment causes in a systematic way. Thereby well-known and already introduced measures are considered as well as prototypes and technologies currently under development. Finally, the potential for new measures is also indicated. These results provide an input for WP 4 to analyse the listed mitigation measures in more detail. The focus of all measures is primarily technology-oriented to gain advantages from automated inspection. The report already provides an approach to run a rough estimation for on-board and wayside monitoring systems.

The work in this task has also provided some practical recommendations, which cannot be structured in an overall manner, but seem to be important enough to be documented to ensure that they are considered during the project. One of these practical examples is the ability of track circuits (which are primarily used for checking the route occupation) to act also for detection of broken rail. During replacement of track circuit to axle counting systems, this functionality gets lost and has to be taken over by some other type of inspection.

D3.2: Analysis & mitigation of derailment, assessment/commercial

Task 3.2 is complete and has produced an excellent review of the scientific aspect on derailments. The deliverable D3.2 contains details of the most actual and significant approaches on the derailment phenomenon, including mechanisms, causes and impacts. An impressive amount of information is synthesised in over 280 pages of high quality scientific documentation, representing a valuable source for scientists working in this domain, both from academia and industry.

The study investigates the influencing factors that lead to derailment through numerical sensitivity analysis. Focus has been placed on Y25 bogied vehicles. Different derailment scenarios have been investigated:

- ✓ derailments in straight and curved tracks;

- ✓ derailments in switches and crossings (S&C) that are an extremely crucial and sensitive component in all railway systems;

- ✓ derailments due to sloshing that, according to track geometry and vehicle speed, may lead to critical wheel unloading;

- ✓ derailments due to wheel and rail failures.

A bottom-up approach was adopted, i.e. through numerical simulation, a detailed technical investigation encompassing a multitude of influencing parameters was carried out with the aim of defining the threshold operational conditions.

The influence of a broad variety of parameters, such as vehicle suspension, track geometry and condition etc., on the risk of derailment has been investigated, especially considering operational conditions known to be prone to derailment (e.g. asymmetrical loading, tank wagons, etc.).

For each derailment mechanism the following steps have been carried out:

- establishment of parametric influence (ranges and cross-influence) for both vehicle and track and magnitudes of influence of the different parameters;

- establishment of threshold parameter values or threshold parameter value combinations;

- comparison of derailment assessment standards;

- overview assessment of existing methodologies and devices for detecting "unacceptable" vehicle parameters.

The analysis tools developed have been employed for analysing how the findings relate to measured operational data. The identified parametric ranges will form a framework to establish detector alarm limits and maintenance/monitoring schemes that prevent limiting stages to be reached in operation.

The report also provides an estimation of commercial impact of preventive measures, in particular for wheel failures and rail failures. The commercial impact is estimated in relation with the findings in previous deliverables, especially D1.2, D2.3 and D3.1.

D3.3: Guidelines on derailment analysis and prevention

This report is aimed at implementation of results from D3.2. It includes information for each derailment scenario studied in D3.2:

- ➢ Brief description of the studies carried out
- ➢ Brief summary of most important conclusions

To support further development of maintenance/monitoring solutions, the guidelines provide indications regarding:

- What needs to be measured/monitored;

- Which measurement/monitoring accuracy is needed;

- Tentative limit magnitudes;

- How measured data should be employed in operational control and maintenance planning;

- Parameters/scenarios suitable for test investigations/validations;

- Input on key parameters in causing derailments, and parameters that should be measured.

WP4: Inspection & Monitoring Techniques

This Work Package was to provide a detailed review and critical assessment of current inspecting and monitoring techniques relating to derailment prevention and mitigation. Inspection and monitoring must be considered for both the freight vehicle and track aspects and the interaction, the 'freight system'. The technology assessment included the existing technical solutions currently available for train ID capturing and consequent association to the inspecting/monitoring tasks. Based on the findings from previous work packages, relevant cost effective solutions to improve the existing inspection and monitoring systems have been developed, including functional and operational requirements.

Table 5 WP4: Task Status Breakdown

Task no.	Task description	Comments and summary of results

4.1	**Survey of Existing Inspecting & Monitoring Systems |** Detailed review and critical assessment of current inspection and monitoring techniques relating to derailment prevention and mitigation.	Gathered and synthesised all the contributions on existing inspection and monitoring systems, to provide an overview of currently used systems. Selection of the relevant technologies aiming at preventing derailments from top causes highlighted by WP1, and a precise description of these technologies. The results are synthesised in the first part of D4.1.
4.2	**Assessment of Existing Inspecting & Monitoring Systems |** Assessment of the survey and inspection of monitoring systems following from previous Task 4.1.	Assessment of selected technologies under defined criteria, using a matrix developed by partners. Initial results already suggest the first proposals of future innovative on-board equipment. Concluded in the 2nd part of D4.1 Both 4.1 and 4.2 have had difficulties in collecting data in general, economic information in particular.
4.3	**Improvement of Existing Inspection & Monitoring Systems |** Identification and definition of functions in existing systems which are missing (gap analysis) or which require further development in order to significantly enhance and improve derailment prevention.	Potential improvements of existing monitoring systems were identified and proposed. Two innovative solutions corresponding to some gaps identified were presented in D4.2, to support the development and testing (in WP6).

Task 4.1 carried out a survey of the existing inspecting and monitoring systems, including vehicle identification. The results of Task 4.1 are synthesised in the first part of D4.1.

Task 4.2 analysed the systems gathered within Task 4.1 and assessed the existing inspecting and monitoring systems, including vehicle identification. The results of both tasks 4.1 and 4.2 have been synthesized in the deliverable D4.1.

Task 4.3 took over the results of tasks 4.1 and 4.2 and considered what functions in existing systems were missing, or which required further development in order to significantly enhance and improve derailment prevention. This has been done by means of a gap analysis.

Task 4.3 was successfully completed and concluded with the milestone *MS4 Workshop to review forward system developments and proposed implementation.* The results have been presented in the deliverable report D4.2.

D4.1: Existing inspection and monitoring survey and assessment

The deliverable aims to provide a detailed review (Task 4.1) and critical assessment (Task 4.2) of current (existing and emerging) inspection and monitoring techniques (including vehicle identification) related to derailment prevention and mitigation.

The study includes, along with a selection of case studies:

- track-based inspection and condition monitoring equipment,
- vehicle-based technologies and specific recording cars with on-board systems, and
- vehicle identification using video or Radio Frequency Identification (RFID).

Data and opinions have been provided for this survey and assessment by various partners involved in WP4: infrastructure managers (UIC, DB and TRAFIKVERKET), academic partners (VUT and UNEW) and suppliers (FAIVELEY, HARSCO, OLTIS and MERMEC). Work Package 4 has also taken input from WP1 (Derailment Impact) on the principal causes of derailment in the EU, and WP3 (Derailment Analysis and Prevention), on related critical parameters. The results of WP4 will

feed into technology integration (WP5), field testing and evaluation (WP6) and operational assessment (WP7).

The deliverable presents an assessment of selected monitoring systems to determine their ability to capture key derailment parameters. The results are presented and some features, advantages and limits of the selected systems are listed. A set of evaluation parameters was generated and a rating scheme developed in order to quantitatively evaluate the systems.

Based on this assessment, Task 4.3 will perform a gap analysis to determine what functions are missing and what technologies require development in order to improve derailment prevention. These results will be described in Deliverable D4.2 ('System enhancements, developments and functional system specifications').

Task 4.1 has reviewed and analysed the inspection and monitoring techniques that are in the tasks' contributing partners' knowledge or that are currently used in their country. This synthesis gives a survey on existing inspecting and monitoring techniques related to derailment prevention and mitigation. The description of systems based on those technologies has been made using Excel spreadsheets that were completed by partners. These descriptions include features such as location, field of application, description, physical principle, unit price, time consumption, communication system, degree of automation. These features form a preliminary assessment of the selected monitoring technologies.

For the purpose assessing the selected technologies within Task 4.2, an assessment matrix has been built and completed by expert partners according to some critical criteria such as: hardware ruggedness, technology platform, standards, cost, and operational limits, cross border interoperability, diagnostic alerts, measurement effectiveness and derailment prevention efficiency.

D4.2: System enhancements, developments and functional system specifications

The main inputs for this deliverable were the results of Task 4.2 (Assessment of monitoring techniques) and of WP3 (critical parameters, combination of parameters). The objective was to make a gap analysis between the thresholds of the critical parameters (WP3) and the accuracy of the currently used monitoring techniques.

Potential improvements of existing monitoring systems were discussed and proposed, and some emerging technologies or promising prototypes to meet these gaps were described. For example, some influencing parameters of the accuracy of wayside monitoring systems measuring quasi-static wheel loads were studied, limitations of existing arrangements are shown and recommendations for future installations were provided.

Moreover, two innovative solutions corresponding to some gaps identified are presented in detail in the deliverable 4.2. They consist in a wayside system based on visual technology able to check the surface defects on wheels, and a sensors system embedded on freight wagons, capable to reduce the risk of a derailment. These innovations have been tested and validated in the framework of WP6.

As a general output, functional specifications for system application aiming to prevent and mitigate derailment occurrences are established to aid development and support testing (WP6). These specifications cover a range of both, wayside and vehicle embedded equipment including, recommendations for technological improvements and/or new technical feature introduction.

In conclusion, the existing situation in Europe regarding the prevention of freight train derailments through implementation of automatic inspection and monitoring systems was considered as acceptable. However, considering the latest technical innovations and developments, there is a significant potential for improvement.

The results of WP4 were further employed by the next Work Packages; WP5 has investigated how some of these innovative monitoring techniques can be implemented related to derailment prevention, WP6 has tested and validated some of these techniques in lab and field conditions, and WP7 dealt with the Life Cycle Costs (LCC) and Reliability, Availability, Maintainability, Safety (RAMS) analysis of the various monitoring concepts identified and analysed in WP4.

WP5: Integration of Monitoring Techniques

This work package was to develop and integrate different wayside and onboard monitoring concepts (including vehicle identification), relating to derailment prevention and mitigation purposes, into railway operation. Monitoring concepts include a description of how to integrate various monitoring systems and techniques into the wider railway system. The monitoring concepts contain aspects such as interfaces, Safety Integrity Level (SIL) definitions, protocols, data transfer, data base concepts, alerts and action plans etc. Suitable concepts have been developed and selected on the basis of RAMS and LCC-analysis. This led to information about normalised costs in connection with purchasing, operating and maintaining of monitoring devices in correlation with assessment of safety enhancement. On this basis, different business cases had to be developed in order to support information for wider industrial implementation.

Table 6 *WP5: Task Status Breakdown*

Task no.	Task description	Comments and summary of results
5.1	**Development & Integration of Inspection & Monitoring Concepts |** Development and integration of different monitoring concepts taking into account the survey, assessment and suggested improvement of monitoring techniques from WP4.	Existing systems of cross-border data exchange of monitoring were reviewed and novel concepts discussed. Identification and analysis of prerequisites for pan European data exchange (generic approach) and monitoring concepts for Way Side Train and On board Monitoring Systems
5.2	**Classification and Migration of Inspection & Monitoring-Concepts |** To collect results from the different WPs and assess each in relation to RAMS and LCC analysis in order to rank the various concepts developed by Task 5.1.	Developed business cases on the basis of D5.1 and other D-RAIL deliverables' results. Identified and discussed the boundary conditions. Analysed the data exchange issues, with respect to data types, data interpretation, protocols, compatibility between systems, etc. Analysed different strategies for the implementation and exploitation of the current systems.

WP5 activities have started before the scheduled time in order to assure that the outcomes from other WPs are complete and possible to use in WP5. The work started with the conceptual design of a data model for cross-border data exchange of monitoring systems. A state-of-the-art analysis of cross border data exchange of operational systems was initiated to assist progress towards the objective of integration of newly or existing monitoring systems.

The work in Tasks 5.1 and 5.2 continued with the development of a model concept for cross-border data exchange of monitoring data and the definition of the current formats being used for the data exchange.

Relevant topics such as existing boundary conditions including a state of the art of monitoring concepts and relevant regulation in Europe were collected. Prerequisites for pan European data exchange (generic approach) and monitoring concepts for Way Side Train and On board

Monitoring Systems were developed. Legal aspects and benefits from using monitoring data were discussed. An Implementation strategy including time and costs was integrated. Different examples were integrated into deliverable reports D5.1 and D5.2 in order to show the feasibility of developed concepts.

Different set of interventions with the highest impact on derailment reduction and potential for cost savings were selected together with WP7 for further analyses. Based on the set of selected interventions several case studies with available data were used for the application of risk analysis, risk management, RAMS and LCC assessments.

The discussions between WP 5 and WP 7 and the relevant RAMS and LCC inputs from WP 7 ensured to define and to evaluate business cases and implementation scenarios in order to reach the targets set out for the D-RAIL project (reduce the occurrence of freight train derailments within Europe by between 8-12% and derailment related cost reductions of 10-20%).

The results of the investigations within WP5 were presented in two deliverables. The overall WP5 philosophy and the content of deliverables D5.1 and 5.2 are shown below in *Figure 4.*
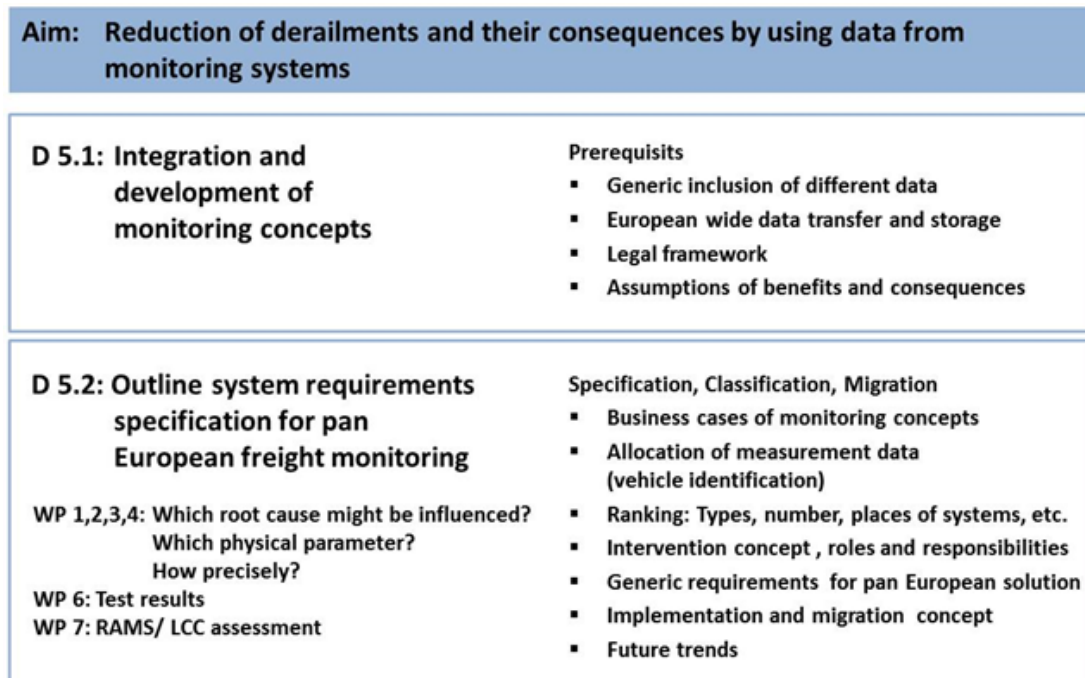
Figure 4 WP5 deliverables' content

D5.1: Integration and development of monitoring concepts

This deliverable presents the results of Task 5.1 and it aimed to discuss and define relevant concepts in a sense of prerequisites for the development and assessment of pan European monitoring concepts where data from monitoring systems are used in order to prevent derailments.

The report presents the interactions between the technical components of the monitoring network of an infrastructure manager, as well as the communications between infrastructure managers (IM) and railway undertakings (RU), respectively entities in charge of maintenance (ECM) and vehicle owner (VO). The document presents concepts for fixed *wayside train monitoring systems (WTMS)*, which mainly deal with defects on the vehicles. On board monitoring systems that deal with defects of vehicles, infrastructure and their interaction are discussed in D5.2. Their approaches are significantly different.

The discussion about recently implemented monitoring concepts shows the variety of nationally driven concepts. Significant experience already exists and every country is facing different needs from their perspective and some examples are presented in the document. Not only the legal framework differs from country to country but also other relevant boundary conditions do (like track alignment due to geographical conditions or the amount of valuable infrastructure, etc.). However, local and dedicated agreements used by two countries to manage border issues would be enhanced when standards and unified rules are defined to solve multi border and multi country situations (pan European). Additional input from other activities and/or related projects show how intense different partners are involved in the enhancement of the railway system. It is seen, that harmonisation across Europe is a key factor for success.

The classic distinction concerning the roles and responsibility of actors like IM, RU and VO are strongly influenced by the use of monitoring systems. This implies that new legal concepts may be needed in future. Relevant aspects were discussed in chapter 5, which can be used as a guideline for this political issue.

The deployment of systems by an infrastructure manager that monitor the condition of a railway undertaking's vehicles may be construed as a risk transfer. This could have a chilling effect on safety since IM can evade the risk transfer by not deploying WTMS and thus miss an important tool in augmenting safety. A regulatory climate that facilitates and does not hinder WTMS deployment is thus necessary. Additional legal risks are related to intentional acceptance of residual risk (by less restrictive thresholds or less than perfect system densities) or unintentional risks due to human error, deficient equipment, maintenance windows. The document presents a simple and tested approach to address these risks.

Furthermore a methodology was developed to assess potential benefits when using monitoring concepts for preventing derailments. One aim was to assess the operational impact of using monitoring devices to prevent derailments. Further comparisons where performed in order to classify the impact for different parties.

Apart from the benefits related to derailments, the study shows that infrastructure managers also derive significant benefits from deploying WTMS in an integrated approach. These include improving security of the railway transport, improving the infrastructure availability, decreasing infrastructure damage, lowering the total train delays, better timetable performance, better customer relationships, better insight into network usage by gathered statistics and trend analyses.

Railway undertakings and vehicle owners can also derive benefits if they receive data from the IM: information on the quality of the operated rolling stock, delay reductions, maintenance cost optimisation, intervention planning after defect detection, providing delay estimations to customers and in some cases for certification.

In order to allow a pan European usage of monitoring data three different concepts were compared. Data from different monitoring devices, technologies and suppliers have to be integrated in an exchange procedure. A comprehensive outline presents and compares three potential concepts:

 (a) national driven solutions;

 (b) *longterm perspectives including harmonizing intervention procedures and values,* and

 (c) *a generic approach which allows the use of existing devices.*

Relevant aspects like the type and amount of data are also covered as well as the exchange process between different countries. It is seen that a "generic approach" that is further described in the report shows the most benefits. Furthermore it is seen that new technological possibilities (such as

the internet) support this relevant topic. Easy to implement algorithms in line with TAF and TAP TSI are the baseline for future developments presented in D 5.2.

Some immediate gain can be obtained by direct intervention on vehicles, but a much higher gain can be obtained by an integrated approach, as it allows to follow vehicle characteristics over time, permits an intervention mode that balances needs for safety with operational aspects (eliminating false positives while keeping true alerts) and allows for more robust uptimes and higher system densities at the same cost. In addition, the integrated approach allows for an exchange of data between involved parties. It has to be discussed if the exchange is only between IM or how to include also RU, NSA and/or VO.

The following types of information could be exchanged: *measurement data, pre-analysed measurement data, measurement data and interpretation rules and/or operational data.* Depending on the data types to be exchanged, conditions on standardization are different (peer-to-peer versus centralized exchange, non-unified versus harmonized protocols). It is understood that many systems are already deployed and in use which restricts the degrees of freedom significantly. The practical experience today is with peer-to-peer non-unified exchange, but protocol harmonization is certainly a desirable step. Use cases for data exchange are border-crossing trains, trend analyses of train operations and infrastructure usage, use of different and new monitoring systems as well as maintenance optimisation.

D5.2: Outline system requirements specification for pan European freight monitoring

The second WP5 deliverable deals with specifications for different business cases. They are classified and assessed with the help of RAMS and LCC in order to quantify the impacts. Implementation strategies are discussed taking the situation in European into account.

The report describes different measures for derailment prevention and their framework for implementation. It combines results from D 5.1 and other deliverables of the D-RAIL project. Different business cases based on these results and some others are discussed, prerequisites are developed and analysed.

Starting from the foreseen changes in the railway freight sector up to 2050 and the possible influence on derailment prevention measures, the report analyses how to group different derailment causes and mitigation measures in order to evaluate which technologies that could be used for detecting a higher risk of this specific derailment cause is investigated. Different monitoring concepts for on-board devices are introduced and discussed in chapter 4.

Due to the high complexity of the task and in addition to D 5.1, boundary conditions are identified and discussed. This implies not only questions regarding how to link measurement and/or assessment values to individual vehicles and their components (WTMS-perspective) or to individual locations (OMD-perspective), but also discussions about different intervention scenarios.

All these inputs influence the development and discussion of different business cases and a discussion about their implementation. Although only an average situation in Europe can be examined, every individual party in the railway sector gains widespread information, when evaluating their individual risk situation.

It was observed that basic IT questions, such as transaction protocols, safe communication interfaces, firewalls, server solutions have been solved. The interesting fact is that the mentioned examples use protocol descriptions based on xml. This type of protocol is very flexible for any extension. Meantime, the analysis shows that operational data have to be combined together with technical data derived from WTMS and/or OMD, and last, but not least, combined with individual

assets. Here shall be the future development. It was shown that this topic is not treated sufficiently in any of the existing regulations or even in any of the TSI.

Actions due to potentially improper vehicle and/or infrastructure states are only possible and economical beneficial for the whole railway sector if the data exchange includes more than the bilateral contracted parties. Measured and interpreted quantities have to lead to actions, either to prevent derailments or to save money due to state dependent maintenance. One precondition for this is to enhance the legal framework. When implementing the business cases proposed by WP5, every actor needs a clear legal basis for knowing about their duties and responsibilities. Even if a pan European implementation of all proposed concepts will take some time, a transition period is needed. The framework of the successfully implemented general railway law needs some extensions, when using data from WTMS/OMD. This gap is not filled by the Regulation (EU) N° 1078/2012 on the CSM for monitoring.

Another critical aspect related to data exchange deals is the interpretation of the content of the data. Data from different systems, supplier, locations, etc. shall be transmitted in future among all parties and across borders. Although it is expected that the harmonisation of intervention concepts and thresholds in Europe will take more time (or it may be impossible in some cases, due to comprehensible reasons), a first interpretation of the data can be harmonised. A generic approach was developed for this purpose, which would enable to integrate different types of measurement data.

Based on the risk and LCC assessment a suitable number of additional systems was provided in order to reach the proposed aim of reduction in 2050. The installation strategy is then dependent on the individual risk assessment, as pointed out above. Therefore it is estimated, that countries with an already existing detection network will increase the number of installations only marginal until 2050. It is expected that here the emphasis is more on data use and data exchange. One beneficial action will be to change towards state dependent vehicle inspection and maintenance routines. Enhancements in maintenance regulations will be developed and implemented. Those activities will also be beneficial for countries with a recent low level of automation. They can benefit from these developments when they start installing their detection network.

WP6: Field Testing & Evaluation

This work package was to validate, through testing on selected test sites, that the proposed changes to the freight system reduce the propensity for derailment and improve safety.
To validate the freight system improvements, two test locations were instrumented for both track and freight vehicles: NewRail test site in Barrow Hill (UK) and VUZ test facility in Velim (Czech Republic). During the tests new technologies were evaluated to determine the step changes in safety performance required for derailment prevention. The results of the test provided feedback to the derailment analysis to validate the initial selection. This ensured that recommendations have been effectively delivered

Table 7 *WP6: Task Status Breakdown*

Task no.	Task description	Comments and summary of results
6.1	**Testing to support numerical simulations |** To support modelling and simulation in WP3 and validate the key assessment parameters.	The influence of lateral rail bending on rail foot crack growth was investigated on the flat curve of radius 150 m at the VUZ test site. In addition, the risk of rail climb for two-axle vehicles was investigated through a test on the flat curve of radius 150 m at

		the VUZ test site in which lateral and vertical forces and longitudinal strain of rail foot edge were measured.
6.2	**Pilot Technology Testing |** The pilot testing of existing and new technologies to support the implementation of full field trials at test facilities.	MERMEC wheel surface defects inspection system was tested in Barrow Hill. The wayside non-contact wheel surface inspection system is capable to perform an automatic visual inspection of the wheelsets in service, by using high definition cameras to detect shelling, spalling, flat spots, or cracks on the tread of the wheel. The system was tested in three stages: 1. The system was verified and data from a variety of vehicles were collected (22nd Apr to 2nd May 2014) 2. The system was left running to capture data automatically and tune the image processing (May – Sep 2014) 3. A broken flange defect was replicated on the wheel of a test vehicle, and data were captured for the validation of the system (Sep 2014)
6.3	**Field Testing of Integrated Technology Systems |** The core testing activity at the VUZ test facility, implementing selected concept(s) prepared from the pilot technology testing.	Two monitoring systems were tested at VUZ Test Centre in Velim: 1. FAIVELEY Transport instability sensoring system - an on-board system designed to detect bogie stability problems and, if required, to issue an alarm according to the detected level. 2. DAKO mechanical derailment detector - a newly developed device which is designed to detect derailment and reduce the impact of derailments. Faiveley sensoring system was installed on the bogie frame of a flat wagon, and tested on both normal and abnormal operational conditions (five selected types of instabilities in vertical, lateral and longitudinal direction were replicated). Data of accelerations were gathered and analysed in order to prepare the software of the system. DAKO derailment detector was installed on a tank wagon and tested on simulated derailment conditions (pushed over wedges places on both rails).
6.4	**Cross Border Testing |** Utilisation of existing selected vehicle and wayside monitoring derailment technologies including potential device(s) enhancements to demonstrate performance and processes for railway operation across member states.	Installation and cross border testing was performed in a single location, between Germany and Sweden. One train equipped with RFID-tags according to these specifications was monitored while running from Sweden to Belgium through Denmark and Germany. The regularly operating train was used as a test train, in order to exchange data of ALC- and RFID-readings obtained in Sweden and in Germany.
6.5	**Testing Evaluation |** Evaluation of the results obtained from the field tests and the cross border assessment.	Results obtained from the field tests in the Czech Republic (VUZ) and the UK (NewRail), and the cross border assessment in Germany (DB) were scientifically evaluated and also compared with the results of simulation and modelling.

Brief overview of overall WP6 results

- **Task 6.1** – *Testing to support numerical simulations*

A 3D FE track model was developed and calibrated towards stresses and deflections measured at a test track section. Different train speeds and loading modes were accounted for. The calibrated numerical track model allows for the prediction of bending stresses in the outer rail foot also for load conditions outside the studied range.

The high values of the lateral bending stresses predicted under more severe conditions imply that the influence of lateral bending cannot be neglected regarding crack propagation (and fracture) of

rail foot cracks. Consequently, more rigorous inspections of rail foots in track sections with high lateral loads (e.g. sharp curves and switch blades) can be motivated.

- **Task 6.2** – *Pilot Technology Testing*

The MERMEC wheel checker did not interfere with the normal operation of rail vehicles. The only impact on normal operations was that drivers were warned about potentially distracting lights; however no issues related to this were reported. This means that the equipment could be successfully integrated into a national network without modifications to vehicles or the infrastructure being required.

- **Task 6.3** – *Field Testing of Integrated Technology Systems*

  FAIVELEY Transport instability sensoring system

Large efforts will be needed to organise review and prepare the software for the detection sensor. Data treatment will be carried out as follows:

- data review by PC based mathematical analysis software

- algorithm for detection simulation

- implementation of software algorithm in the sensor

- verification in the lab by a dedicated test bench.

  DAKO derailment detector

The functionality of the prototype was successfully verified during the testing period when the device was not activated during normal operations and was activated when the vertical acceleration of the wagon headstock reached 9.3 g. After achieving successful test results, the device could be ready for a trial operation on wagons of Czech freight rail operators.

- **Task 6.4** – *Cross Border Testing*

The project objective to install and to test a WTMS-related application including RFID and a cross border data exchange between Sweden and Germany was fulfilled. A new RFID-reader was installed in Tornesch, some kilometres north of Hamburg, Germany. An ALC was already in use there, in order to detect trains running southbound towards Hamburg. Here, the test train coming from Sweden on its journey to Belgium could be detected, in order to compare measurements with the readings in Dammstorp, Sweden.

The results were reported within three deliverable reports.

D6.1: Analysis of tests for the validation of numerical simulations

This deliverable has reported the work carried out within the Task 6.1 of WP6.

A key issue in need of investigation through testing is the influence on lateral rail bending on rail foot crack growth. The motivations came from WP3. The evaluation of the loading of a (hypothetical) foot edge crack from a lateral bending of the rail was performed in three steps:

1. *Measurement of rail loading and deflection*

The measurements were carried out on the flat curve of radius 150 m at the VUZ test site (Czech Republic) from 19th to 23rd May 2014. Lateral and vertical rail forces as well as longitudinal stresses on foot edges were measured by VUZ whereas rail deflection and torsion measurements were performed by PoliMi portable device. During tests two-axle and four-axle wagons at different (low) speeds and under two load conditions operated through the curve.

2. *Development of track model and its validation and calibration towards test results*

A 3D FE model consisting of two rails and 12 sleepers, corresponding to 7.52 m of track was developed by partner Chalmers. Vertical and lateral wheel loads from measurements by VUZ served as an input for the initial model with track parameters adopted from experience. The model was then calibrated towards measured data in that predicted and measured longitudinal stresses and rail deflections were used to tune these parameters.

3. *Numerical modelling for the prediction of the lateral and vertical bending stresses under higher loads and train speeds than those measured*

Due to the presumed model linearity and the assumption of an elastic material response, the loading in the simulations was extrapolated towards higher levels which indirectly corresponds to higher speeds, axle loads etc.

D6.2: Analysis of vehicle and wayside monitoring technology field tests

This report presents the results of the work carried out within Tasks 6.2 and 6.3 as well as the evaluations in Task 6.5 of WP6.

Three newly developed monitoring systems were selected and tested on the basis of the findings of WP3 (analysis), the existing technology evaluation (WP4) and integration of monitoring techniques (WP5). The deliverable report presents the equipment which were tested, the tests set-up and conditions and their results.

1. *MERMEC wheel defects checker*

The system, which was developed by partner MERMEC, was tested within Task 6.2. This is a wayside system placed near the track in order to monitor and inspect the running surface of the wheel by means of vision systems. The images are captured by a digital camera aided by a lighting system. The main target of the wheel checker in order to reduce the occurrence of derailments is a detection of defects and breaks of the wheel flange. Other targeted defects are considered to be all on the running surface of the wheel, such as shelling, spalling, flat spots etc. This device has been installed at the NewRail test facility in Barrow Hill, at the most intensively used track on the site, in April 2014. The first stage of tests was realised in the period from 22nd April to 2nd May 2014, during which the system was verified and data from a variety of vehicles were collected. In the second stage (May – September 2014) the system was left running to capture data automatically and tune the image processing. For the third stage in September 2014 a flange defect on the wheel of a vehicle was created to replicate a flange broken in service; the vehicle ran through the system and data were captured.

2. *Faiveley instability sensoring system*

This system, which was developed by partner Faiveley, was tested at the VUZ test facility (Czech Republic) on the small and large circuit within Task 6.3. It is an on-board system designed to detect bogie stability problems and, if required, to issue an alarm according to the detected level. At the design level, the sensor is able to log the 3 axis acceleration rates and detect high acceleration patterns in the time domain. The system was installed on a flat wagon on which five selected types of instabilities were re-produced (in vertical, lateral and longitudinal direction). The test period was from 30th June to 4th July 2014. The gathered data of accelerations were analysed in order to prepare the system software for the detection.

3. *DAKO mechanical derailment detector*

This device was developed and provided by an external organisation (DAKO), and was also tested at the VUZ test facility. The DAKO detector is a newly developed device which is designed to

detect derailment and significantly reduce the impact of derailments. The principle of the detector is to measure a vertical acceleration of a vehicle headstock. The detector is mounted on both headstocks. When a shock higher than 11.5 g with frequency up to 100 Hz occurs on the wagon headstock, the device is activated and makes the train brake. The system was installed on a tank wagon which was pushed over wedges placed on both rails in order to simulate a derailment. The test period was from 12th to 14th August 2014, during which the function of the system was verified.

D6.3: Analysis of vehicle and wayside monitoring technology field tests

This deliverable report presents the work carried out within Task 6.4 and the evaluation of its results in Task 6.5 of WP6.

The project aimed to install and test a WTMS-related application including RFID and a cross border data exchange between Sweden and Germany. A new RFID-reader was installed in Tornesch, some kilometres north of Hamburg, Germany. There, an ALC was already in use, in order to detect trains running southbound towards Hamburg. At this track section, many regional and freight services operate. All freight trains are running via Denmark to the Nordic countries. Here, the test train coming from Sweden on its journey to Belgium could be detected, in order to compare measurements with the readings in Dammstorp, Sweden. The same WTMS-equipment (ALC and RFID) was used on both sites, but the suppliers of the ALC in Sweden and Germany were different.

Although no previous knowledge about this specific RFID-reader developed at TRV existed in DB, the successful installation and setting up was possible due to valuable and cooperative support. A new data receiving service and new data bases were established at and by DB, while TRV implemented a web-service for data exchange. After some adjustments of the new system a test phase could start. The different runs of the regular operating test train could be detected and readings matched very well. Not only the total number, but also the order and placement of RFID were the same for both detectors in Sweden and Germany. Additionally ALC results for the weight of the train as well as the individual vehicles and axles matched very well. Therefore, the here implemented data exchange can be used for further applications.

WP7: Operational Assessment & Recommendations

This work package was to provide a summary of the key derailment findings, and use RAMS analysis for best and worst case scenarios to identify the impact of vehicle monitoring on the reliability, availability and safety of the railway system. Economical assessment of monitoring concepts, including migration with regard to LCC and social economic effects and risk assessment for relevant vehicle states and monitoring scenarios, have been undertaken. An estimation of derailment reduction and impact of the various monitoring concepts is provided.

This Work Package was highly relevant to rail freight operators since many of them have significant economic problems. It is therefore important to know the economic consequences of proposed technical solutions.

Table 8 WP7: Task Status Breakdown

Task no.	Task description	Comments and summary of results
7.1	**Methods for Technical and Economic Analysis |** Survey and analysis of existing investigations regarding RAMS and economic studies on derailments and derivation of	• Survey and analysis of existing investigations regarding RAMS and economic studies on derailments and derivation of methods and key parameters for risk analysis, assessment and decision making. • Analysis methods, key parameters, scenarios and boundary

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	methods and key parameters for risk analysis, assessment and decision making.	conditions.
7.2	**RAMS and LCC Management and Boundaries |** Development and supply of principles for LCC and RAMS analysis.	• Common understanding of LCC and RAMS; • Development of a framework and boundary conditions for RAMS & LCC analysis • Definition of key input data and safety targets for RAMS and LCC analysis; • Approach for risk analysis and risk management according to CSM-RA; • Adaption/Definition of migration scenarios; • Support of WP's in collection of RAMS & LCC relevant data for monitoring systems.
7.3	**RAMS Analysis |** Technical analysis of the existing situation and the local and global monitoring concepts.	• RAMS analyses of the proposed monitoring systems (WTMS); • RAMS analysis to identify the impact of inspection and monitoring on the Availability, Reliability and Safety; • Risk analyses and risk assessment of various monitoring concepts (business cases defined by WP5) in line with CSM-RA; • Impact of the current and estimated increase of freight traffic; • Impact of the impact of future carrier demands on the RAMS of System; • Comparison of different cases and concepts of monitoring systems (existing situation, local & global); • Identification of the influence of potential use of monitoring systems in Maintenance procedures on systems RAMS; • Definition of migration scenarios; • Combined technologies targeting different type of derailment causes.
7.4	**LCC-Analysis |** Economic analysis of the existing situation and the local and global monitoring concepts.	• Economic analysis of the existing situation and the local and global monitoring concepts; • Development of LCC models; • Economic impact of monitoring systems (LCC assessment to identify the economic impact of monitoring systems) including socio-economic effects; • Effect of current and estimated increase of freight traffic; • Impact of migration scenarios on LCC; • Comparison of different cases of monitoring systems in terms of reduced derailment costs (20% LCC reduction); • Estimation of derailment reduction in relation to number of monitoring systems; • Economic effect of use of monitoring systems in maintenance process.
7.5	**Recommendations & Findings |** Summary of Tasks' 7.2 and 7.4 results, pointing out the balance between technical and economic benefits to provide input for WP8.	• Summary of the technical and economical findings of WP7; • Summary of the findings of all WP's concerning the use and implementation of monitoring systems; • Recommendations for the use of monitoring systems for vehicle based on the achieved results; • Description of reliable implementation scenarios (local-national / global-international) the use of monitoring systems; • Preparation of input for the guideline "The use/implementation of monitoring systems"; • Description of open points and further work/research recommendations.

The WP7 interfaces are illustrated in ***Figure 5*** below. WP7 is co-related to all the other work packages, but has direct interdependencies in particular with WP2, 3, 4 and 5. Therefore, the timing of the planned work was essential for achieving the objectives.
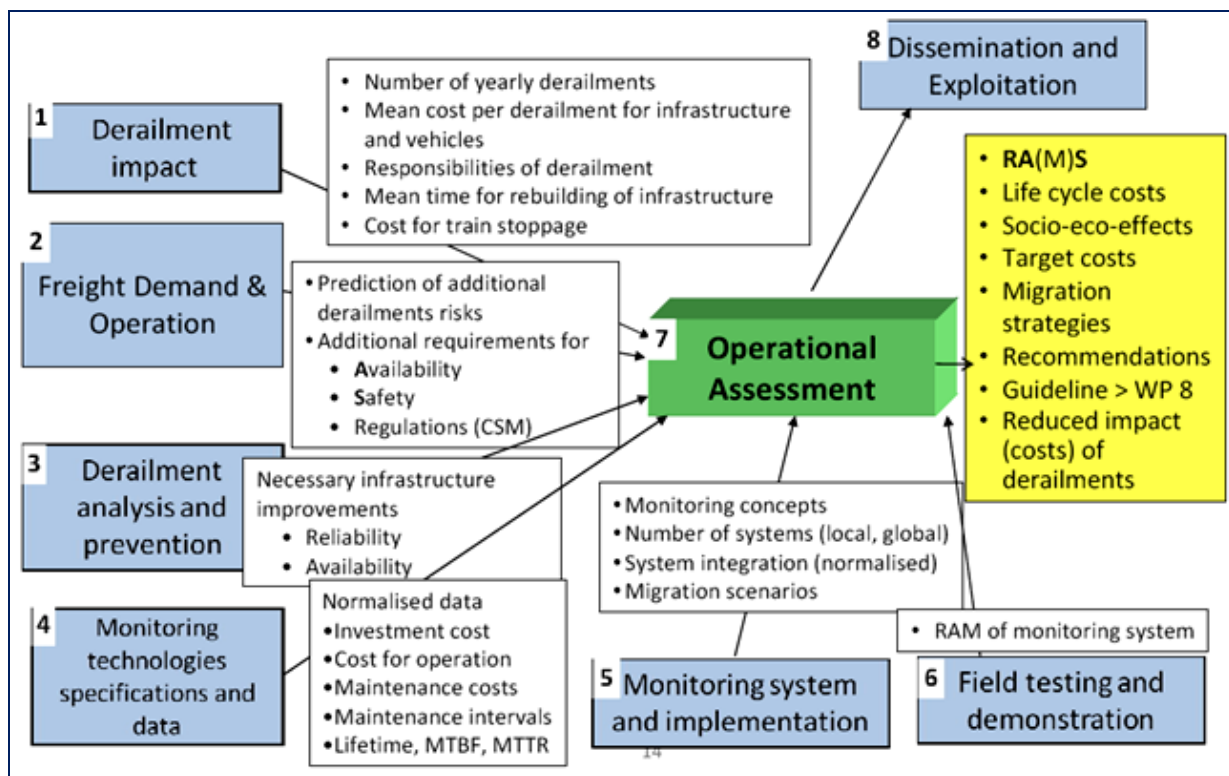
Figure 5 *D-RAIL project interfaces and data flow to WP 7*

A conceptual framework for RAMS and LCC analyses has been produced for the application of RAMS and LCC assessments of the inspection and monitoring systems related to derailment.

RAMS and LCC Management and related boundaries have been established as a base for the required RAMS and LCC assessments such as the establishment of common understanding of RAMS & LCC, finalisation of the conceptual framework for RAMS and LCC analyses and boundary conditions, definition of key input data and safety targets and definition of the approach for risk analysis according to the CSM-RA. Several templates were developed in order to collect the RAMS and LCC relevant data from the involved partners and other WP's respectively.

A study on existing investigations regarding RAMS and economic studies on derailments including the survey of used methods, key parameters, scenarios and boundary conditions have been carried out.

In this regard a theoretical assessment of methodologies for risk management, RAMS and LCC analyses was performed. Based on these study findings a method appropriate for the D-RAIL task was developed.

Different set of interventions with the highest impact on derailment reduction and potential for cost savings were selected for further analyses. Based on the set of selected interventions several case studies with available data were used for the application of risk analysis, risk management, RAMS and LCC assessments.

Therefore, by performing technical and economical assessments through RAMS and LCC analyses, the targets set out for the D-RAIL project (reduce the occurrence of freight train derailments within Europe by between 8-12% and derailment related cost reductions by 10-20%) have been achieved.

WP7 results were presented in detail in five deliverable reports.

D7.1: Existing derailment RAMS and economic studies and D-Rail approach

This deliverable sets out from the outcomes of previous Work Packages, as well as the ERA study carried out by DNV, and recent research projects by UIC, DB, TRV, SBB, OBB and RSSB. These inputs are reviewed and summarised in the first part.

The deliverable also reviews and summarises existing RAMS and economic studies related to derailments. The report provides a good survey of relevant methods and approaches for risk analysis, risk assessment and risk-related decision-making. This overview shows that different countries have different views and approaches on how optimal RAMS performance may be reached in an economical and safe way. This highlights the fact that monitoring/mitigation strategies will govern your actions, and that there are most likely not only a single optimal (in terms of RAMS and LCC) solution.

The report then outlines the "D-RAIL approach". The initial analysis of different data related to the number of derailments and their costs shows the significant differences between countries in Europe. This was also observed for today's use of monitoring systems. Here future demands and potential modifications are dealt with. In particular the work in WP3 have identified 37 potential modifications and 29 means of influencing the risk of derailments, which will be further scrutinized and contrasted to monitoring potentials identified in WP4 and WP5. The report then outlines how evaluation of input data in terms of LCC and RAMS is to be carried out in WP7 and how this is linking the data flow in D-RAIL together.

D7.2: RAMS-analysis and recommendation (technical focus)

The report describes the findings of risk assessment and RAMS analysis based on the developed conceptual framework on RAMS and LCC.

In respect to the risk assessment, the top derailment causes identified in WP1 and the effects on derailment reductions from WP2, as well as the assessment matrix for most promising technical interventions from WP4 were combined to derive a shortlist of possible measures. 55% of the total impact from interventions can be achieved with the examined monitoring systems, namely Hot Box and Hot Wheel Detector systems (HABD), Axle Load Checkpoints (ALC) and Track Geometry Measurement Systems (TGMS). No other techniques were studied in WP7, because they lack effectiveness compared to the studied interventions. For hypothetical new interventions, no input data for RAMS, LCC and risk assessments could be provided by the relevant work packages.

In the next step, the actual risk assessment and risk analysis with reference to the Common Safety Method on Risk Evaluation and Assessment have been conducted. Since no European reference implementation exists, the risk assessments were independently carried out using the SBB and RSSB methodologies. The key inputs considered were the estimated increase of freight traffic towards 2050 from WP2 and potential implementation scenarios and estimated implementation costs from WP5. Risk figures related to freight derailment and risk reduction benefits due to the proposed risk control measures have been calculated using actual SBB and RSSB safety risk data.

It was initially remarked that none of the three measures would be considered reasonable under the ALARP principle, or any other standard. The outcome of both risk assessments would appear to disagree with current railway practice in many EU states, where HABD's, ALC's and measurement wagons are widely used. However, this apparent contradiction is an artefact of the D-RAIL scope limited to freight derailments, which denies economies of scale as well as synergies with reduction of passenger risks, typically exploited by infrastructure managers. A reduced case, based on the

amount of additional systems deployed for freight only, was subsequently evaluated which shows a positive outcome for ALC and TGMS.

In order to protect against derailment due to a hot axle condition, high level reliability performance of HABD is vital. Higher reliability of HABDs contributes positively to detect any hot axle condition, and lower the derailment likelihood and consequence. As shown in the RAMS analysis, field reliability can be improved through an applicable and effective maintenance strategy. The application of selected case studies shows that the framework of RAMS and LCC is operational and provides a robust approach in underlying the RAMS concept and building the basis for proposed RAMS analysis to deal with derailment and prevention/mitigation of derailment.

A migration approach is described, based on two initial scenarios. One scenario is traffic with high density and/or high speed reflecting the situation of highly mixed traffic lines or high speed passenger traffic, whereas the second scenario is traffic with low density and/or low speed represented by secondary lines. The starting point is also different for European countries: many of them use technology-intense monitoring and intervention due to high traffic density, others rely on human monitoring. It seems likely that an increase in traffic as predicted in WP2 will shift most countries to technological solutions.

D7.3: LCC analysis and recommendation (economic focus)

This deliverable focuses on the economic assessment of the proposed inspection and monitoring systems by application of cost-benefit and LCC analyses. Established methods for LCC analysis are adapted to the D-RAIL project scope and requirements. A full cost breakdown was developed based on actual operational experience and data from infrastructure managers. Based on the business cases for monitoring in D5.2 – notably the number of sites and placement strategies – costs for Europe could be derived.

The safety assessment performed in D7.2 of WP7, and based on data collected from WP2, WP3, WP4 and WP5, forms a component of this economic analysis, but additional benefits are also incorporated in the economic assessment. The effect of increase in freight traffic volume by 1.5% annually up to 2050, estimated in WP2, has been taken into account in the economic analyses. The effectiveness of each of the proposed systems in reducing frequency of freight derailments, and the associated reduction in risk, has already been estimated in D-RAIL report D2.3. Given that, safety benefits based on derailment cost reduction were analysed through risk assessment in D7.2.

More specifically, WP7 performed cost-benefit analyses and LCC analyses to assess the economic value of the proposed inspection and monitoring systems. The reduction in derailments in relation to number of monitoring system is determined through LCC analyses. This fact is reflected in the evaluation of the business cases developed by WP5 by indicating the additional monitoring systems necessary to achieve 20% LCC reduction set out for D-Rail. Even though a causal link between the required number of additional monitoring systems and their life cycle costs (LCC) is not absolutely definitive. Also the combination of measures targeting different type of derailment causes is discussed based on intervention reports.

Based on the outcomes of cost - benefit analyses, it was concluded that Axle Load Checkpoints (ALC) and Track Geometry Measurement Systems (TGMS) are beneficial. Axle load checkpoints have a remarkably good ratio between costs and benefits. Track geometry measurement systems show an even better efficiency ratio in the cost-benefit analysis. The outcomes of cost-benefit analyses considering hot axle box detection (HABD) show that the costs in both scenarios are very high in relation to the benefits and thus unfavourable, due to reasons such as: the placement strategy is a density-based approach; the safety benefits are rather low, which can be explained by the already widespread use of HABD in many countries and the low maintenance benefits.

Contrary to this, HABD brings financial benefits in the LCC analysis. The LCC analyses demonstrate that the 20% LCC reduction can be achieved with fewer of additional monitoring systems concerning HABD than assumed by the WP5 business cases. This means that cca. 330 additional HABD devices (instead of 790 assumed in the business cases of WP5) would be sufficient to achieve 20% LCC reduction. Similar results were obtained for ALC, i.e., cca. 210 additional ALC installations are necessary to reduce the LCC by 20%. The difference between the WP5 and WP7 results is explained by the fact that WP5 has initially estimated the number and location of additional monitoring systems as a starting point, in order to be further assessed through LCC analysis afterwards.

In conclusion, a higher focus on the implementation of ALCs would lead to more financial benefits. So the installation of additional ALCs generates more benefit than installing additional HABDs, a significant number of these being already use.

Regarding TGMS, it was shown that the LCC reduction by 20% cannot be achieved considering the given boundary conditions defined in the business cases of WP5. The reason is mainly the low number of avoided derailments due to the assumed measuring accuracy of 60%. Provided that the measuring accuracy of TGMS is 90%, the rate of derailment reduction increases and the benefit in terms of 20% LCC reduction can be achieved. But it is difficult to estimate the risk reduction, also because no quantitative data could be provided within D-RAIL in this area. The risk reduction can only be estimated as it is not only dependent on detection, but also on intervention.

It is well known that TGMS has the highest potential maintenance cost optimisation, so these systems become very interesting from a maintenance perspective in terms of better usage of measurement data for prediction of trend analysis and performance of the right intervention. In addition, the transition from corrective maintenance to enhanced condition-based and predictive maintenance would be enhanced.

The LCC analysis reveals the enormous potential maintenance cost optimisation based on the efficiency gains of using monitoring data to perform Condition-Based Maintenance instead of Time- or Interval-Based Maintenance. It is noteworthy that the quantitative results agree with operational experience in the U.S., where maintenance plays a very prominent part in the business cases for monitoring systems.

Three different aspects of migration were considered: technical migration of equipment, migration towards an integrated approach facilitating data exchange, and the shift from manual surveillance towards automated equipment that is due to today's inhomogeneity of the risk landscapes (traffic densities, speeds, topography, climate, etc.)

While these economic potentials are immediately available for infrastructure, the identification problems remain a hurdle for vehicles, although RFID-based schemes are in discussion for quite some time. Since these discussions lie on the interface between infrastructure managers bearing the costs and railway undertakings/entities in charge of maintenance deriving the benefits, an active role of supranational bodies would help develop these potentials within a short timeframe for the railway system and society as a whole.

D7.4: Industry guidelines/standard for implementation of monitoring techniques

This report summarises the main findings of the D-RAIL project related to the implementation of monitoring systems and provides guidelines and recommendations based on the outcomes of previous results of WP7. It was proved that more than half of all derailments (and a share of 75% of the costs) are addressed by only three types of interventions: hot axle box and hot wheel detectors, axle load checkpoints and track geometry measurement systems. While new technologies and their

application were studied, notably regarding onboard devices, the targets may be achievable with existing technologies if properly deployed, developed and coordinated.

The RAMS analysis includes decision making on selection of equipment according to the reliability and maintainability, evaluation of an applicable and effective maintenance strategy and assignment of the optimum and cost effective interval. Based on the outcomes of LCC analyses, axle load checkpoints and track geometry measurement systems show a good ratio between costs and benefits. The outcome of cost-benefit analyses considering hot axle box detection are not favourable due to the density-based placement strategy, the already widespread use and the low maintenance benefits.

The divided role and responsibilities of IMs and RUs poses new questions due to the use of monitoring systems. Installed WTMS owned and managed by the IMs are increasingly stopping non-compliant vehicles of the RUs and ECMs, principally with the aim of protecting the infrastructure from damage (i.e. not to prevent derailments). The present legal framework has to be adapted for future needs since roles and responsibilities of the actors like IM, RU and ECM change. Most notably the IM gains better insight into individual vehicles requiring maintenance than the RU and ECM, whereas the impression arises that RU/VO lose their technical competence in the field of wheel-rail interaction. This should however not be construed as a risk transfer, because that would have a damaging effect on safety. Infrastructure managers could evade the risk transfer by not deploying WTMS and thus miss an important tool in augmenting safety. A regulatory climate that facilitates and does not hinder WTMS deployment is necessary. Additional legal risks relate to intentional acceptance of residual risk (by less restrictive thresholds or less than perfect system densities) or unintentional risks due to human error, deficient equipment, maintenance windows.

Every country is facing different challenges due to the diverse legal framework and safety management approach, but also other relevant boundary conditions are significantly different. This translates into infrastructure-specific alarm and intervention thresholds and intervention actions, for which a full harmonization is unlikely. Railway undertakings and vehicle owners suffer from this situation, which can only be addressed by data exchange. The generic approach developed in D-Rail, based on exchanging raw data and a recommended interpretation, is a simple solution for the required exchange between IMs as well as from IM to RUs and ECMs. From the IM perspective, it allows integration of different existing equipment and multiple types and generations of WTMS. All actors can also derive non-safety benefits such as information on the quality of the operated rolling stock, reducing delays, certification, optimisation of maintenance costs, intervention planning after defect detection and providing delay estimations to customers.

The cost-benefit analysis reveals the significant potential maintenance cost optimization based on the efficiency gains of using monitoring data to perform Condition-Based Maintenance instead of Time- or Interval-Based Maintenance. It is noteworthy that the quantitative results agree with operational experience in the U.S., where maintenance plays a very prominent part in the business cases for monitoring systems.

<ins>D7.5: Scientific and technical review by acknowledged scientists and railway experts</ins>

The final WP7 report contrasts the quality assurance plans towards actual implementation throughout the project. Throughout the D-RAIL project, a thorough quality assurance has been applied to certify that deliverables maintain a high scientific and technical standard. The framework for this is described in the deliverable D9.1.

However, the adopted quality assurance was far more thorough than what was indicated in D9.1. In particular all essential deliverables have been subjected to an extra two-stage internal review in addition to the internal quality assurance in the working group. Further, relevant bodies such as the

ERA and the UIC-TEG have been given the opportunity to comment upon deliverables related to their fields.

Finally it can be noted that the work of D-Rail is now being introduced in scientific journals and working groups for future operational recommendations and codes. In this process further reviewing will result.

4.1.3 The potential impact (including the socio-economic impact and the wider societal implications of the project so far) and the main dissemination activities and exploitation of results

A sustainable, efficient and safe rail freight transport in Europe is a key element of a successful and competitive economy, in meeting consumer demands and in creating a sustainable and significant growth in jobs and wealth for European citizens. Rail freight transport is expected to grow by some 50 % (in tonne- kilometres) between 2000 and 2020, in line with forecasts in the Commission White Paper entitled *'European transport policy for 2010: time to decide'* (COM(2001)0370).

Within the EU, freight transport has doubled within a period of 30 years and forecasts are still equally strong. This growth of freight traffic is explained by changes in intercontinental trade and removal of barriers within the European continent. In the past decades growth in cross-border flows, in particular in East–West trading, was twice as high as the growth in domestic transport. The growth in freight transport, which has been some 30 % faster than GDP growth between 1995 and 2005 has mainly been the result of an increase in road and air transport relative to other modes of transport. The rail freight mode did not experience the same level of growth.

This is not an acceptable trend especially in light of increasing congestions in the road and air modes. In addition this does not take advantage of the environmentally friendly nature of rail transport (such as CO_2 emission issues etc.). To shift the current trends, D-RAIL addressed mainly several of the main competition factors of rail freight transport: reliability, safety, efficiency and cost-effectiveness by identifying innovative and effective means of preventing derailments. The outcome of D-RAIL is to enhance safety of freight operations.

The importance of these measures is underlined by the forecast in the ERRAC Strategic Railway Research Agenda 2020: to include significant growth in container traffic. As the size of container ships increases it becomes less and less feasible to use road transport alone to move the containers to their final destination. Instead rail will have to take an increased share in order to allow the EU's major ports to continue to operate efficiently. To this end, cost-efficiency, reliability and safety are crucial. D-RAIL results are a key ingredient in assuring this.

D-RAIL potential impacts in relation with the work programme

In 2009 the European Railway Agency (ERA) identified that substantial benefits for quality of service and safety of the railway freight transport may be achieved by a significant reduction of freight train derailments. It was also considered that small or fragmented improvements of existing safety measures might be neither significant nor sustainable in regards of the foreseeable evolution of railway freight transport, as described in 'A sustainable future for transport' [COM(2009) 279/4], and the expected increase of railway traffic. What is necessary is to reduce the number of derailments and the associated derailment rate to balance the effect of railway traffic increase on the derailments numbers.

D-RAIL outcomes are expected to result in a step-change in safety with respect to the risk of rail freight derailments and a resulting reduction of number of derailments and derailment rate. These impacts result from a structured approach to derailment prevention using new and existing

inspection technologies effectively and innovatively. The D-RAIL project approach consists of a seven step process. The current status was established by an analysis of existing derailment data and knowledge (WP1). The growth and the evolution in freight transport until 2050 was further projected (WP2) together with its impact on derailments. The fundamental mechanisms leading to derailments have been analysed and key parameters identified (WP3). Current inspection and monitoring technologies to ensure safe operating conditions have been charted (WP4). Needed inspection and monitoring technologies have been identified, developed and integrated (WP5) and the most promising solutions were tested (WP6). Finally, the expected reduction of derailment occurrences and impacts has been quantified and LCC and RAMS benefits of the mitigating strategies evaluated (WP7).

D-RAIL research has taken into account previous research, the EU legal framework (including Railway Safety and Interoperability Directives), as well as the tasks carried out by the European Railway Agency in this field in order to ensure seamless introduction of proposed changes.

The project outcomes comprise practical strategies and actions to decrease derailments both in the short-term and in the long-term. These strategies have been designed to operate within the EU legal framework and leverage the work carried out by the European Railway Agency. The expected benefit is an absolute reduction of derailments and their impacts. Further, the structured approach facilitates a seamless introduction of proposed changes in the European rail (freight) system.

Thus, the long-term measures and results are to achieve derailment prevention and mitigation solutions that contribute to the optimisation of rail freight services, considering the technical and logistics requirements of the customers' supply chain: reliability, punctuality, quality, safety, and reduction of costs (including maintenance and inspection costs). The development of such solutions will determine a set of impacts on both the transport sector and the whole EU economic system. The expected impacts, sorted by category from a micro to a macro level, are listed below.

Impacts on rail freight operations

Freight train derailments have a major impact on railway operation, including both freight and passenger train operations. As such, any reduction in the number or severity of the derailments represents a significant benefit to all railway parties (train operators, infrastructure owners, vehicle owners, terminal operators, shippers, etc. In addition, this allows for the establishment of common safety and other relevant standards throughout Europe.

For train operators

- The more advanced monitoring systems developed through D-RAIL will result in lower levels of derailment which will in turn reduce service disruptions, train delays, loss of equipment and goods, incidents involving dangerous goods (RID), save fatalities and reduced maintenance costs. The resulting improved levels of reliability will reduce the number of incidents which have serious implications for the whole railway system.

- D-RAIL approach and results are able and efficient to support the integration of existing and new monitoring technologies with existing railway control and operating systems, to facilitate implementation and use throughout Europe.

- D-RAIL overall results provide added value on vehicle conditions that effect operating costs using criteria developed through state-of-the-art simulation and field tests.

- Outcomes on the integration and implementation of existing technologies allow for identification of unsafe vehicles and rapid return to service.

For infrastructure owners

- The D-RAIL project solutions allow vehicles to run at higher speeds with reduced risk of derailment, which will result in a reduction in the complexity of operation of a mixed traffic railway. Better use of existing infrastructure will further result in increased capacity and increased traffic flow.

- Identification of vehicles that generate excessive loadings that might cause derailments and also cause damage to the track structure will reduce maintenance activities.

- Considering D-RAIL measures at border crossings and other network access points, the wayside monitoring systems will identify and stop unsafe vehicles before entering the connected network.

- The implementation of novel D-RAIL monitoring systems will reduce infrastructure damage from the derailments.

For vehicle owners

- D-RAIL solutions provide added value on vehicle conditions that effect maintenance costs using criteria developed through state-of-the-art simulation and field tests.

- Identification of recurring vehicle problems associated with certain classes of vehicles.

- The reduction in derailments will reduce vehicle repair costs and loss of goods.

- Identification of vehicles that generate excessive loadings will allow for better long-term management of vehicle maintenance.

For terminal operators

- The more advanced monitoring systems developed through D-RAIL will result in lower levels of derailment which will in turn reduce service disruptions in the terminals.

- D-RAIL guidelines will help improve loading practices that can result in the safe even loading of freight vehicles to limit imbalance and loss of products.

- D-RAIL recommendations and overall results create a more competitive environment for freight logistics solutions on rail.

For shippers

- Improved safety will increase the attractiveness of rail transport by reducing loss and damage due to derailments.

- Improved safety will result in more efficient and more reliable movement of goods, and reduce costs.

For partners directly involved in the project

- The D-RAIL experience has clearly enhanced skills and knowledge in relation with inspection and monitoring systems, freight vehicle design, modelling and simulation etc.

- D-RAIL led to identification of strong research and development partners to work with, enhancing the networking efficiency of players in different sectors.

Overall

- The implementation of the D-RAIL project solutions will result in improved safety, which will increase the overall attractiveness of rail freight as a transport mode.

- The improved derailment performance of technologies and solutions which have been developed in the D-RAIL project will result in significant reductions in operational costs for the vehicle operator and the infrastructure owner.

- The increased competitiveness will allow premium rail freight services to operate in market sectors previously lost to other modes.

Impacts for the transport sector

- The implementation of D-RAIL outcomes will help to promote the attractiveness of the rail freight mode as part of the overall European transportation network.

- Improved rail safety will result in enhanced environmental management.

- D-RAIL solutions are capable to help the improvement of relevant surface transport features increasing the quality and competitiveness of rail transport services considering parameters such as price attractiveness, environmental friendliness, punctuality, frequency, real time information or leisure and work during travel time will encourage modal shift.

- Preparation of freight rail for the challenges of market in 2050 to meet the increasing demands for freight transportation.

- D-RAIL outcomes in relation with the vehicle identification technology and management will aid information flow and will also increase the effectiveness of the overall logistic chain across different modes of transport.

Impacts for the whole EU socio-economic system

Ultimately, the implementation of D-RAIL outcomes will improve safety and make the train service more competitive with road transport, thus enhancing the competitiveness of rail transport in existing and previously unexploited markets. These effects will:

- determine a modal shift to rail from other modes, lowering the environmental impact of transport operations;

- contribute to optimising the cost-efficiency of transport operations and all the other sectors involved;

- contribute to increasing the efficiency of labour market;

- contribute to the economic development of Europe and to its competitiveness by creating a more competitive environment where all the actors play.

In this framework, D-RAIL fulfils the expected list of impacts as shown below in *Table 9.*

Table 9 D-RAIL activities and results with respect to expected impacts

Expected impacts/outcomes	D-RAIL activities and results
Analysis of existing knowledge on derailments mechanisms and complement it, in particular in regards combined causal effects.	WP1 (Derailment impact) provides a comprehensive review of existing freight derailments including combined causal effects derailments. The severity and impact on railway operations has also been assessed to understand the economic implications for damage to vehicle/infrastructure and disruption. WP3 (Derailment analysis) has identified and evaluated through

	modelling and simulation the causal effect mechanisms and the key contributory factors associated with derailments. This is to include combined causal effects for both the freight vehicle and track system.
Define and describe the foreseeable (macro) features of the railway freight system towards a freight target system in 2050, taking into account the European Transport Policy, available studies and research on freight logistic and relevant trends of sector economics as well as railway technology developments.	WP2 (Freight demand and operation) has evaluated the trends for railway freight of the future towards the freight target system of 2050. This embraced future European rail policy and strategy for freight including movement, logistics, sector economics and the likely impact on forward operation of technologies. The improved derailment performance of the freight vehicles will result in significant reductions in operational costs for the vehicle operator and the infrastructure owner. The increased competitiveness will allow premium rail freight services to operate in market sectors previously lost to other modes. D-RAIL helps to promote the attractiveness of the rail freight mode as part of the overall European transport network. Improved rail safety will result in enhanced environmental management.
Define cost effective scenarios, integrating system changes and new safety measures, in order to reach the proposed target system(s) and the expected reduction of derailment occurrences and impacts	D-RAIL has identified and analysed different wayside and onboard monitoring concepts (including vehicle identification) related to derailment prevention and mitigation. Further systems' developments and integration strategies were proposed based on a comprehensive assessment of different technologies and safety requirements. Suitable concepts were developed and selected on the basis of RAMS and LCC-analysis to support information for wider industrial implementation. The expected result is a measureable reduction in significant derailment categories.
Demonstrate and validate (field tests) the feasibility of the most innovative system changes/safety measures within the proposed time scale.	Novel innovative safety technologies have been demonstrated and validated under test for both track and freight vehicle(s) and to support measurement of the combined interactions in WP6. Both existing and new technologies including telemetry and monitoring outputs have been assessed to determine the step changes in safety performance required for derailment prevention.
Define long term scenarios, integrating RAMS (Reliability, Availability, Maintainability and Safety) and LCC (Life Cycle Costs) analyses, for the development of a future railway freight system integrating a significant reduction of derailment occurrences and impacts.	In WP7, RAMS analysis has identified the impact of vehicle monitoring on the reliability, availability and safety of the railway system. The economic assessment of monitoring concepts which were developed in WP5 has considered the implementation strategy, LCC and social economic effects, and risk assessment for relevant vehicle states and monitoring scenarios.

In conclusion, the impact of D-RAIL is not limited to the rail transport sector, but could easily leak to the whole EU socio-economic system, and translate into a sound knowledge base for the future further improvements of all the actors directly and indirectly involved by the project.

Dissemination activities

The findings of the research have been widely disseminated to various stakeholders.

This was undertaken by the consortium members who already form a wide geographical, demographic and industrial spread across Europe. UIC was the project lead partner concerning these activities and was able to provide assistance in promoting and disseminating the findings of the research on a pan-European and International basis. Outreach and marketing of the research findings were presented throughout the project to a wide variety of stakeholders and engineers to ensure industry awareness.

In concluding the research findings, recommendation for improvements to existing European standards for freight operation has been assessed and provided. The research was reported in relation to the future freight target system for 2050, and how the findings of the research will benefit economic and technological developments in future freight operation.

The project website was developed and launched in the first months of the project. The initial website was further updated and new sections were added in order to host relevant information.

D-RAIL partners have carried out an intensive dissemination of the overall project in a series of significant events, as summarised below in *Table 10*.

Dissemination has been a driven process. Some dedicated presentations have been presented to standardisation bodies and have been targeted through groups existing under the UIC umbrella such as TEG (Track Expert Group), PoSE (Panel of Structural Experts) and TTIG (Train Track Interaction Group). Some deliverables have also been transposed into practical guidelines. The coordinators also aim to establish working groups that will continue working on and refining the D-RAIL results after the project completion.

The project has organised two general public workshops. The first one was held at the midterm of the project while the second one has taken place in late September 2014. Additionally, a specific seminar has been organised in November 2014.

Project logo:

Project website:

http://d-rail-project.eu/

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Table 10 *Summary of the main D-RAIL dissemination events*

Date	Venue or location	Event	Dissemination title	Dissemination type
12-Jul-12	UIC Paris, France	ERRAC WP04 Final Workshop on Railway Safety and Security	FP7 EU funded project D-RAIL	General presentation
18-Sep-12	Berlin, Germany	INNOTRANS 2012 Exhibition	FP7 EU funded project D-RAIL	General presentation
04-Oct-12	Nis, Serbia	RAILCON 2012 Conference	Development of the Future Rail Freight System to Reduce the Occurrences and Impact of Derailment	Paper, presentation and fliers
30-Jan-13	UIC Paris, France	Meeting with two UIC groups: Track Expert Group (TEG) and Panel of Structural Experts (PoSE)	FP7 EU funded project D-RAIL	General presentation and discussion
08-Oct-13	Eslöv, Sweden	Track Expert Group (TEG) Meeting	Training session on D-RAIL WP3 results	General presentation and discussion
25-27-Nov-13	Sydney, Australia	WCRR 2013 Congress	Holistic overview of freight train derailments in Europe: causal and impact analysis	Oral presentation
			Investigation and guidelines on use of monitoring technologies for preventing and reducing the occurrence of freight train derailments	Oral presentation
			Triple rail freight demand by 2050 in EU27- realistic, optimistic or farfetched imagination?	Oral presentation
			Types of rolling stock in 2050 in EU27 to meet Transport White paper 2011 target	Poster
14-17-Apr-14	Paris, France	TRA2014 Conference	What mitigation technique should be implemented to reduce freight vehicle derailments by 2050	Oral presentation
			Overview of freight train derailments in the EU. Causes, impacts, prevention and mitigation measures	Oral presentation
16-Oct-14	Edinburgh, UK	The 2nd Workshop of Ballasted Track between Japan and the UK	Freight train derailments in the EU. Causes, impacts, prevention and mitigation measures	Oral presentation
05-Nov-14	London, UK	RRUKA's 3rd Annual Conference	Development and testing of wheel checker for derailment prevention	Oral presentation
12-Nov-14	Stockholm, Sweden	Final D-RAIL seminar	D-RAIL project results and way forward towards implementation	Presentations, key note speakers, discussions