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INNOTRACK

Integrated Project (IP)

Thematic Priority 6: Sustainable Development, Global Change and Ecosystems

D1.4.6 - A report providing detailed analysis of the key railway infrastructure problems and recommendation as to how appropriate existing cost categories are for future data collection

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PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	X

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Glossary

Abbreviation/acronym	Description
IM	Infrastructure Manager
LCC	Life Cycle Costing
EC	European Commission
R+D	Research and Development
RAMS	Reliability, Availability, Maintenance and Security
SP	Sub-project
SP1	Sub-project 1
WP	Work package
WP1	Work Package 1
ÖBB	Oesterreichische Bundesbahnen
CD	České Dráhy a.s
RFF	Réseau Ferre de France
DB	Deutsche Bahn
ADIF	Administrador de Infraestructuras
BV	Banverket
NR	Network Rail
ProRail	ProRail

1. Executive Summary

The European Commission-sponsored INNOTRACK project is aimed at reducing the life cycle cost of track maintenance by 30%. It will achieve this by developing innovative maintenance methods and technologies, targeted on those aspects of track maintenance that cause the most problems and lead to the highest costs. It will also use life cycle costing (LCC) methods to assess the cost impact of the new technologies and decide whether they provide value for money.

This report describes two studies carried out in support of these aims. The first was a study to identify the principal track problems facing Europe's IMs. The report explains the methodology used to do this and the results obtained.

The second was a study to identify whether there is a common maintenance cost structure among INNOTRACK IMs, capable of supporting LCC analysis. The report describes the analysis of existing cost structures and identification of a set of principal European maintenance cost categories.

Principal Track Problems

The study involved close working with, and substantial input from, the INNOTRACK partner IMs, namely:

- ADIF - Administrador de Infraestructuras
- ÖBB - Oesterreichische Bundesbahnen
- CD - České Dráhy a.s
- RFF - Reseau Ferre de France
- DB - Deutsche Bahn
- BV - Banverket
- NR - Network Rail
- ProRail - ProRail

In essence, the methodology adopted for the study involved asking each INNOTRACK partner IM to hold two internal workshops designed to try and identify the main track problems and rank them in order of importance. In outline, the methodology had eight basic steps as follows:

1. Create a template to guide discussion in the Phase 1 IM Workshops;
2. Hold the Phase 1 Workshops to identify the main track problems, their underlying causes, possible solutions and methods of evaluating performance;
3. Consolidate the results of the Phase 1 Workshops based on the reported problems (ignore underlying causes at this stage;
4. Rank the problems based on the frequency with which they were reported and omit from the ranking those problems reported by less than two IMs;
5. Create a template to guide the discussion in the Phase 2 IM Workshops, based on the ranked list of problems from Phase 1 and include associated underlying causes;
6. Hold the Phase 2 IM Workshops to rank problems and underlying causes from the point-of-view of cost;
7. Consolidate the results of the Phase 2 IM Workshops, and finally;
8. Create a list of track problems and underlying causes prioritised on the basis of cost impact.

Analysis of the results from the Phase 1 Workshops identified the following track problems to be the most important based, on the number of IMs experiencing that particular type of problem. The problems are listed in descending order of importance:

- Track: bad track geometry
- Rail: cracks and fatigue
- S+C: switch wear

- Substructure: unstable ground
- Joints: insulating joint failure
- Rail: corrugations
- Rail: wear
- Structures: major line closures
- Fasteners: worn/missing pads
- Sleepers: renewal optimisation
- Culverts/pipes: flooding
- Ballast: stone spray
- Ballast: ballast wear
- Rail: low friction/adhesion
- Joints: weld quality
- S+C: common crossings
- S+C: Manganese crossings
- S+C: geometry maintenance
- S+C: loss of detection

Analysis of the results from the Phase 2 Workshops identified the following track problems and underlying causes to be the most important based on their cost impact, again listed in descending order of importance:

Track problems	Causes
Rail: cracks and fatigue	creep forces
Rail: cracks and fatigue	bad wheel/rail interface
Track: bad track geometry	soft sub-structure/bad drainage
S+C: wear in switches	sub-structure
Rail: corrugations	vehicle/track interaction
S+C: cracked manganese crossings	weld quality
S+C: geometry maintenance	optimal maintenance regime?
Sub-structure: unstable	soft sub-structure/wet bed
Track: bad track geometry	sub-optimal maintenance
Track: bad track geometry	wrong/unknown stress free temperature

Further analysis of the Phase 2 results showed there to be a positive correlation between the importance of a track problem as measured by frequency of reporting, and the importance as measured by cost impact.

Maintenance Cost Categories

IMs were asked to list the cost categories they currently use and state the percentage of their maintenance budget allocated to each one. An analysis of this data was then carried out to determine whether a set of cost categories existed, common to all of the INNOTRACK IMs.

Analysis of the initial data found some commonality between the cost categories, but also a degree of variability. Further work was carried out therefore, to remove cost headings used by only to one or two IMs (for example, snow clearance), and to consolidate some detailed costs into higher-level cost categories (for example, consolidating the detailed category of ‘ultrasonic inspection’ into the higher level category of

'inspection'). As a result, the following existing principal cost categories were identified for use in LCC analysis:

- Welding;
- Grinding;
- Inspection;
- Rail Lubrication;
- Track renewal;
- Sub-grade;
- Geometry;
- Drainage, and;
- Minor periodic maintenance.

2. Introduction

The European Commission-sponsored INNOTRACK project is aimed at reducing the life cycle cost of track maintenance by 30%. It will achieve this by developing innovative maintenance methods and technologies, targeted on those aspects of track maintenance that cause the most problems and lead to the highest costs. It will also use life cycle costing (LCC) methods to assess the cost impact of the new technologies and decide whether they provide value for money.

This report describes two studies carried out in support of these aims. The first was a study to identify the principal track problems facing Europe's IMs. The report explains the methodology used to do this and the results obtained.

The second was a study to identify whether there is a common maintenance cost structure among INNOTRACK IMs, capable of supporting LCC analysis. The report describes the analysis of existing cost structures and identification of a set of principal European maintenance cost categories.

The report has four main sections, numbered 3 to 6, in addition to this introduction. Section 3 provides background to the INNOTRACK project and the reasons why it was necessary to carry out the work covered by this study. Section 4 describes the methodologies adopted and section 5 describes the results. Finally, Section 6 concludes with the study's findings.

Diagrams and results tables referred to in the text are provided as figures and appendices at the end of the report

3. Background

It is EU policy to improve the environmental sustainability of transport. This will require a reduction in road transport, with more freight and passengers travelling by rail. To achieve this, rail will have to become more competitive. This issue can only be tackled by increased research and development (R+D) focused on standardisation at the European level.

The European Commission (EC) White Paper on Transport (September 2002) has set ambitious efficiency improvement targets for transport. The railways have responded by:

- Increasing speed and acceleration of trains,
- Increasing train axle loads and traction power, and;
- Introducing more rigid vehicles with greater stiffness.

These innovations have a downside, however, causing more damage to the track and generating higher maintenance costs.

In response to these problems, INNOTRACK has the task of developing ways to reduce the LCC of railway track, while improving the reliability, availability, maintainability and safety (RAMS) characteristics of a conventional, mixed-traffic line. Investment alone will not be enough; significant innovation and technology transfer will be essential. This can only happen with very close co-operation between IMs and industry suppliers. INNOTRACK will therefore, bring these two groups together in a programme of research based on four key topics:

- Track support structure;
- Switches and crossings;
- Rails, and;
- Logistics for track maintenance and renewal.

INNOTRACK is a large project. To facilitate its management, it has been divided into the following seven sub-projects:

- Sub-project 1 (SP1) (Requirements);
- SP2 (Track support – support structures below the level of the rail);
- SP3 (Switches and crossings);
- SP4 (Rails);
- SP5 (Logistics);
- SP6 (LCC assessment and RAMS), and;
- SP7 (Dissemination and training).

The principal objectives of SP1 are:

- To manage the collection of information in a standardised format relating to the types of vehicle and track that result in high cost for maintenance and renewal;
- To categorise the key degradation conditions chosen by the participating IMs, using the concept of ‘track segments’;
- To determine the root causes of these degradation conditions by modelling at an appropriate level;
- To provide technical data to enable the RAMS and LCC benefit of innovative solutions to be determined;
- To develop a relational database of information developed in the SPs, and;
- To verify that the technical solutions have successfully addressed the root causes within the railway system context, and are suitable for a wide range of present and future traffic conditions across Europe.

Information relating to the types of vehicle and track that result in high cost for maintenance and renewal has been gathered in conjunction with the IMs. In addition, each national IM involved in the INNOTRACK project was asked to hold two workshops: the first to identify the most common track problems, and the second to prioritise them in terms of which generate the highest costs. Outputs from the workshops have been used to help focus the work of INNOTRACK sub-projects 2, 3, 4, 5 and 6.

4. Planned Methodology

Principal Track Maintenance Problems

To identify the most common European track maintenance problems, each of the national IM organisations participating in INNOTRACK was asked to hold a workshop to discuss and record their track maintenance experiences (referred to as the Phase 1 Workshop in this report). Invitations went to: Oesterreichische Bundesbahn (ÖBB); České Dráhy a.s (CD); Reseau Ferre de France (RFF); Deutsche Bahn (DB); Administrador de Infraestructuras (ADIF); ProRail (ProRail); Banverket (BV), and; Network Rail (NR).

To ensure that the discussions and outputs from the workshops were consistent across all the IMs, the template shown as figure 1 in Annex A to this report was developed. In essence, the template divided the railway into its principal physical components. The IMs were then asked to identify the symptoms (principal track problems) they were experiencing for each one. They were also asked to suggest the underlying causes of the problems, possible solutions, and methods for evaluating component performance.

The results from the Phase 1 Workshops were consolidated on the basis of the track problems identified: no consideration was given to underlying causes at this stage. The problems in the consolidated list were then placed in order of importance, based on the frequency with which they were reported by the workshops: the higher then number of workshops reporting the problem, the higher the asumed importance.

IMs were then asked to hold additional workshops (referred to as the Phase 2 Workshops in this report) to identify which of the problems in the consolidated list were most important from the point-of-view of cost. To provide a common basis for workshop discussions, the IMs were provided with the consolidated list of problems derived from the Phase 1 Workshop, but with the addition of the appropriate underlying causes (see Figure 11 of Annex K). The list contained only those track problems identified by two or more of the IMs in Phase 1: the assumption being that a problem identified by only one IM was unlikely to be of great importance from a cost reduction point-of-view.

The results from the Phase 2 Workshops were brought together into one consolidated table based on Figure 11 mentioned above. The consolidated results were then analysed to create a prioritised list of track problems and underlying causes. The problems at the top of the list were those identified as having the greatest impact on track maintenance costs and therefore, perhaps, offering the greatest potential for cost savings using innovative new maintenance techniques

The process steps described above are summarised below as follows:

1. Create a template to guide discussion in the Phase 1 IM Workshops;
2. Hold the Phase 1 Workshops to identify the main track problems, their underlying causes, possible solutions and methods of evaluating performance;
3. Consolidate the results of the Phase 1 Workshops based on the reported problems;
4. Rank the problems based on the frequency with which they were reported and omit from the ranking those problems reported by less than two IMs;
5. Create a template to guide the discussion in the Phase 2 IM Workshops, based on the ranked list of problems from Phase 1 and including the underlying causes;
6. Hold the Phase 2 IM Workshops to rank problems and underlying causes from the point-of-view of cost;
7. Consolidate the results of the Phase 2 IM Workshops, and;
8. Create a list of track problems and underlying causes prioritised on the basis cost impact.

Maintenance Cost Categories

With regard to checking the suitability of existing maintenance cost categories for LCC work, IMs were asked to list the categories they currently use and state the percentage of their maintenance budget allocated to each one. An analysis of this data was then carried out to determine whether a set of cost categories existed, common to all of the INNOTRACK IMs.

5. Results

5.1 Results of Phase 1 IM Workshops

INNOTRACK IMs were asked to identify the principal track problems that they face, together with the underlying causes, possible solutions and methods of evaluating maintenance performance. The results of this exercise are shown in the following appendices to this report:

- ADIF: Annex B;
- RFF: Annex C;
- BV: Annex D;
- DB: Annex E;
- ProRail: Annex F;
- ÖBB: Annex G, and;
- NR: Annex H

The original request for IMs to hold the Phase 1 Workshops was made at a meeting in Paris on Wednesday 4th October 2006, attended by representatives from DB, CD, ÖBB, RFF and NR. BV was unable to attend, but had already participated in development of the workshop template and was therefore, very aware of the process. ADIF and ProRail were also unable to attend, but received a similar, shorter briefing to the one given on the 4th, at the INNOTRACK Kick-off meeting in Paris on 6th October 2006.

Some IMs found it easier than others to hold the Phase 1 Workshops. For internal reasons associated with major reorganisation of Czech Railways, CD was unable to hold its workshop and therefore, did not provide any data to this exercise. The other INNOTRACK IMs provided output from their workshops on the following dates:

- ADIF: 16th January 2007;
- RFF: 27th February 2007;
- BV: 4th October 2006;
- DB: 7th February 2007
- ProRail: 1st February 2007
- ÖBB: 16th November 2006
- NR: 4th October 2006

The consistency of workshop output in terms of quantity, quality and presentational format, varied substantially across the IMs. The output received from each IM is described in outline below:

- ADIF: A comprehensive set of data addressing key problems, underlying causes, possible solutions and evaluation methods for most of the component groups listed on the workshop template. Generally, several problems were listed for each of the main component categories. Additional notes were provided for some of the problems. The workshop template was used as the format for presentation of the results;
- RFF: A very limited set of data, with problem identification restricted to the major components; for example: rail, sleepers, ballast. In most cases only one problem was identified for each component group. For some of the problems data was provided on possible solutions and evaluation methods, but there was confusion over the classification of problems and underlying causes. Additional notes were not provided for any of the problems listed. An edited version of the workshop template was used as the format for the presentation of the results;
- BV: A comprehensive set of data addressing key problems, underlying causes, possible solutions and evaluation methods for most of the component groups listed on the workshop template. Generally, several problems were listed for each of the main component categories. Additional notes

were provided for some of the problems. The workshop template was used as the format for the presentation of the results;

- DB: Comprehensive data provided for the principal track components (rail, ballast, switches and crossings, drives and lockings, ballast, drainage/sub-grade, and system issues). Data covered problems, underlying causes, boundary conditions and potential solutions. Additional notes were provided for some of the problems, but these are not included in this report, because of lack of space. Problems were assessed and rated according to their operational and economic impact on maintenance. The ratings were from 1 to 4, where 4 indicated the highest impact. The data was presented as an Excel spreadsheet in a format based on the workshop template. The data was provided in German, requiring translation into English;
- ProRail: A comprehensive set of data addressing key problems, underlying causes, possible solutions and evaluation methods for most of the component groups listed on the workshop template. Generally, several problems were listed for each of the main component categories. Additional notes were provided for some of the problems. The workshop template was used as the format for the presentation of the results;
- ÖBB: A very limited set of data extracted from the minutes of an ÖBB internal meeting held to discuss the INNOTRACK project as a whole. The data lists a small number of problems without reference to the track components described in the workshop template. The data does not state underlying causes, possible solutions or evaluation methods. There were no additional notes. The data was provided in German, requiring translation into English;
- NR: A comprehensive list of drivers of track maintenance cost was provided, and a small number of possible solutions were also provided

In order to facilitate the drawing of Europe-wide conclusions from the workshops, the results were consolidated into one table shown as Figure 7 in Annex J to this report. Due to the variable consistency of workshop output, consolidation required some interpretation of individual IM results when assigning them to the consolidated list of track problems. Also, in cases where the description of a problem given by an IM was not clear, that problem was omitted from the consolidated list. The number of interpretations/omissions was small and was not felt to have de-valued the consolidated results as a basis for drawing conclusions on Europe-wide track problems.

The table in Figure 7 lists the full range of problems identified and shows the IMs affected by each one. It does not, however, attempt to show the underlying causes of each problem; this is dealt with as part of the Phase 2 IM Workshops.

Figure 8 of Annex J has a histogram showing the frequency with which various problems were reported by IMs. The problems are listed on the Y-axis of the histogram, with each entry stating firstly the track component involved, and then the problem itself. The principal problems and the percentage of IMs reporting each one were as follows:

Problems	Frequency of reports
Track: bad track geometry	75%
Rail: cracks and fatigue	75%
S+C: switch wear	75%
Substructure: unstable ground	62.5%
Joints: insulating joint failure	50%
Rail: corrugations	37.5%
Rail: wear	37.5%
Structures: major line closures	25%
Fasteners: worn/missing pads	25%

Problems	Frequency of reports
Sleepers: renewal optimisation	25%
Culverts/pipes: flooding	25%
Ballast: stone spray	25%
Ballast: ballast wear	25%
Rail: low friction/adhesion	25%
Joints: weld quality	25%
S+C: common crossings	25%
S+C: manganese crossings	25%
S+C: geometry maintenance	25%
S+C: loss of detection	25%

5.2 Results of Phase 2 IM Workshops

INNOTRACK partner IMs were asked to prioritise on the basis of cost, the track maintenance problems and underlying causes identified in Phase 1. The results are shown in the following appendices to this report:

- ADIF: Annex L;
- RFF: Annex M;
- BV: Annex N;
- DB: Annex E;
- ÖBB: Annex P, and;
- NR: Annex R

The initial request to IMs to hold the Phase 2 Workshops was made by email dated 31st January 2007. As with the Phase 1 Workshops, some IMs found it easier to comply than others. This time, in addition to CD, ProRail was unable to provide input to this part of the project. The other IMs submitted the results of their workshops on the following dates:

- ADIF: 15th February 2007
- RFF: 27th March 2007
- BV: 19th March 2007 (re-issued in June 2007 with amendments)
- DB: 7th February 2007 (included in Phase 1 Workshop)
- ÖBB: 1st March 2007
- NR: 21st April 2007

The template issued to guide the Phase 2 Workshop discussions (see Figure 9, Annex K) originally envisaged that IMs would rank each problem and underlying cause from 1 to 5, with 1 signifying the most important. Once the workshops were underway, however, it was realised that this was an unnecessary level of detail, and that it was easier for IMs to rank each problem from 1 to 4. This late change meant that some IMs supplied rankings based on the 1 to 5, therefore when it came to consolidating the workshop results, the ranking for each problem was changed from 1 to 4, with the original 5 being incorporated within the new 4.

The output received from each of the participating IMs is described below:

- ADIF: Output provided as requested;
- RFF: Output provided using a draft of the Phase 2 consolidated results table, rather than the original Phase 2 Workshop template. All of the problems on the table were ranked, not just those

identified by RFF in Phase 1. Only the problems RFF identified in Phase 1 were carried through to the consolidation table;

- BV: Output provided as requested;
- DB: Output provided on an amended version of the Phase 1 Workshop template, as an output from the Phase 1 Workshop. Originally, DB ranked problems from 1 to 4, with 4 the most important. That ranking was reversed to ensure compatibility with the rankings provided by the other IMs;
- ÖBB: Output provided as requested;
- NR: Output provided using a draft of the Phase 2 consolidated results table. Rankings were provided by both maintenance and renewals specialists. These were incorporated into the consolidated table by taking the most important ranking in each case: for example, if the ranking from Maintenance was 3 and the ranking from Renewal 2, the 2 ranking was entered into the consolidated table

Figure 15 in Annex S to this report shows the consolidated results of the Phase 2 Workshops. The problems are listed in order of importance based on the frequency of IM reporting; the higher the number of IMs reporting the problem, the more important it is. The table also shows the importance assigned by IMs to the problems and underlying causes, based on cost. The table provides a useful format for comparing the two methods of ranking problems. It shows there to be a higher incidence of red and purple shading at the top of the table, while at the bottom orange and yellow shading predominates. This indicates that there is a reasonable positive correlation between the importance of a problem as judged by frequency of reporting, and the importance as judged by its cost impact

A further analysis of the results was carried out to rank each problem and its underlying cause solely on the basis of cost. The results of that exercise are shown in Figure 18 of Annex T to this report. The top ten problems and their causes were as follows:

Problems	Causes
Rail: cracks and fatigue	creep forces
Rail: cracks and fatigue	bad wheel/rail interface
Track: bad track geometry	soft sub-structure/bad drainage
S+C: wear in switches	sub-structure
Rail: corrugations	vehicle/track interaction
S+C: cracked manganese crossings	weld quality
S+C: geometry maintenance	optimal maintenance regime?
Sub-structure: unstable	soft sub-structure/wet bed
Track: bad track geometry	sub-optimal maintenance
Track: bad track geometry	wrong/unknown stress free temperature

5.3 Results of Maintenance Cost Category Analysis

The maintenance cost data received from each of the IMs is shown in Annex U as follows:

- Figure 17: Cost categories and maintenance spend for Banverket;
- Figure 18: Cost categories and maintenance spend for ADIF;
- Figure 19: Cost categories and maintenance spend for CD;
- Figure 20: Cost categories and maintenance spend for ÖBB, and;
- Figure 21: Cost categories and maintenance spend for NR.

Initial inspection of the data showed there to be insufficient agreement among the cost categories used by the IMs to support a quick conclusion on a common set. For example, ADIF included replacement of longitudinal timbers as a separate cost heading in its data, while other IMs did not. Also, some IMs (for example ÖBB) recorded snow clearance as a cost, while others (for example, NR) did not. Finally, most IMs' data had 'Other' costs as a significant proportion of the overall maintenance budget; it was not clear, however, what 'Other' costs actually included.

Work was carried out therefore, to consolidate and simplify the data, in an effort to develop a clearer picture. For example, in the case of ADIF, longitudinal timber replacement was incorporated with sleeper replacement, and ultrasonic inspection was incorporated with inspection. Costs peculiar to only one or two IMs (for example, snow clearance) were removed and the remaining costs normalised to take account of this. Finally, 'Other' costs were removed and again, remaining costs normalised.

The results of this work are shown in Figure 22 of Annex U. The table shows the principal cost categories for each IM, ranked in terms of expenditure, with the category attracting the highest expenditure at the top of the column. In addition, the categories are colour-coded to make it easier to compare between IMs the relative cost rankings. The table shows a reasonably consistent set of cost categories across all the IMs. It also shows, with the exception of ADIF's data, that the cost ranking of maintenance activities is similar between IMs.

Although the cost categories were found to be reasonably consistent across the IMs, a small amount of additional work was done to consolidate the categories further. The results of this are shown in Figure 23 of Annex U. The final set of common cost categories were determined as:

- Welding;
- Grinding;
- Inspection;
- Rail lubrication;
- Track renewal;
- Sub-grade;
- Geometry;
- Drainage, and;
- Periodic.

Figure 23 suggests also how these high-level cost categories could be broken don to provide more detailed cost information.

Figures included in Annex V suggests how the cost categories might be related to the principal track faults identified from the IM workshops.

6. Conclusions

The main track problems based on the frequency with which they were reported by INNOTRACK partner IMs, and listed in order of importance, were as follows:

- Track: bad track geometry
- Rail: cracks and fatigue
- S+C: switch wear
- Substructure: unstable ground
- Joints: isolation joint failure
- Rail: corrugations
- Rail: wear
- Structures: major line closures
- Fasteners: worn/missing pads
- Sleepers: renewal optimisation
- Culverts/pipes: flooding
- Ballast: stone spray
- Ballast: ballast wear
- Rail: low friction/adhesion
- Joints: weld quality
- S+C: common crossings
- S+C: Manganese crossings
- S+C: geometry maintenance
- S+C: loss of detection

The ten most important track problems and their underlying causes, identified by IMs on the basis of their cost impact, were as follows:

Problems	Causes
Rail: cracks and fatigue	creep forces
Rail: cracks and fatigue	bad wheel/rail interface
Track: bad track geometry	soft sub-structure/bad drainage
S+C: wear in switches	sub-structure
Rail: corrugations	vehicle/track interaction
S+C: cracked manganese crossings	weld quality
S+C: geometry maintenance	optimal maintenance regime?
Sub-structure: unstable	soft sub-structure/wet bed
Track: bad track geometry	sub-optimal maintenance
Track: bad track geometry	wrong/unknown stress free temperature

This study has shown there to be a positive correlation between the importance of a track problem as assessed by the frequency of reporting and as assessed by cost impact.

Finally, the study has shown that the cost categories currently used by IMs can form the basis for a general European cost structure. The common, high-level cost categories are:

- Welding;
- Grinding;
- Inspection;
- Rail lubrication;
- Track renewal;
- Sub-grade;
- Geometry;
- Drainage, and;
- Minor periodic maintenance.

7. Annexes

7.1 Annex A: IM Workshop Template

Components	Problems	Causes	Possible Solutions	Evaluation Methods
S+C				
Track				
Joints				
Rail				
Substructure				
Ballast				
Culverts/pipes				
Sleepers				
Fasteners				
General infrastructure				
Vehicles				

Figure 1 - Template Created to Guide IM Workshop Discussions

7.2 Annex B: ADIF IM Workshop - Phase 1 Results

ADIF - INNOTRACK IM WORKSHOP - PHASE 1 (1 of 5)

Components	Symptoms	Causes	Possible solutions	Evaluation methods	Other comments
Switches & Crossings	Break of tail monobloc crossings (end zones for fishplating).	Zone of change of section without timber sleeper support.	To install weldable monobloc crossings.	Discontinuity in track circuit; visual inspection; dynamic and geometric track examination.	Obsolete design (type A). Turnouts for low services with crossings not welded to the rail.
	Reinforced switches.		To install wide web profiles.		Obsolete design (types A and B).
	Break of stock rail.	Initial crack both in the fillet radius between web and foot and in the zone of change of mechanization.	Maintenance and peridocal inspections.	Discontinuity in track circuit; visual inspection; dynamic and geometric track examination.	Turnouts with timber sleepers and undergone a high exploitation.
	Wear and breaks in built-up common crossings.	The fatigue working behaviour isn't the appropriate due to loss of geometry.	To install weldable monobloc crossings.	Discontinuity in track circuit; visual inspection; dynamic and geometric track examination.	Primitive design. Turnouts undergone a mixed exploitation (freight and passenger trains).
	Decrease in gauge and check-rail gauge, wear of check-rail and increase in flangeway rail/check-rail.	Seam on the running edge due to crushing of rail head.	Grinding rail.	Dynamic and geometric track examination.	First generation of turnouts (type C and V) installed in the Mediterranean Corridor: max. speed 200-220 km/h, timber and concrete sleepers (these are not applied to new installations).
		Crushing of nose of crossing.	Manual grinding and re-surfacing by welding.		

ADIF - INNOTRACK IM WORSHOP - PHASE 1 (2 of 5)

Components	Symptoms	Causes	Possible Solutions	Evaluation Methods	Other Comments
Track	Bad Quality of Track Geometry	Track Misalignment because of loss of reference to originally designed track geometry	Working with design geometry and absolute tamping techniques	Graphics from Track Maintenance Machines, Track Geometry Inspection	
		Track Buckling due to incorrect setting of Stress Free Temperature in continuous welded rail	Improvement on Control of SFT during track maintenance works implie	Results and temperatures from track works, SFT control devices based on Barkhausen Noise Technique	
		Vehicle-Track interaction			
		Uneven Settlement of Soft Substructures	Adequate Stabilisation Treatments and Intensive Control of Settlemen	Pressure Cells and Surveying Methods	
Rail	Corrugation	Vehicle-Track Interaction because of coupling on resonant frequencies	Use of soft pads (sleepers or rail pads) to change track frequency	Accelerations Control on Rolling Stock (on Axle Boxes, Bogies and Car Bodies)	
			Preventive, corrective and proactive grinding		
		Wheel Flats or Oval Wheels	Intensive Inspection of Rolling Stock		
	Wear	Vehicle-Track Interaction (specially on sharp curves	Asymmetrical Grinding, Oiling	Rail profile control based on continuous laser or other optical devices inspection	
		Incorrect Rail Inclination	Intensive control on rail pad disposition		
	Cracks, Rail Breaks	Development because of Metallic or Gas Inclusions	Intensive control on rail manufacturing processes	Ultrasonic Rail Inspection	
			Intensive Inspection of Rolling Stock	Track Impact Detectors on Spot Locations	
		High dynamic forces applied in Vehicle-Track Interaction	Intensive control of Track Geometry (specially spot track faults)	Ultrasonic Rail Inspection, Track Geometry Inspection, Accelerations Control on Rolling Stock (on Axle Boxes, Bogies and Car Bodies)	

ADIF - INNOTRACK IM WORKSHOP - PHASE 1 (3 of 5)

Components	Symptoms	Causes	Possible Solutions	Evaluation Methods	Other Comments
Rail (continued)		Incorrect setting of Stress Free Temperature in continuous welded rail	Improvement on Control of SFT during track maintenance works implied	Results and temperatures from track works, SFT control devices based on Barkhausen Noise Technique	
	Rolling Contact Fatigue	Vehicle-Track Interaction			
	Squats, Wheel Burns	Sliding Wheels specially when vehicles are accelerating or braking		New digital images processing techniques based on continuous image obtaining on vehicles of track components	
	Bad Thermit Welds	Bad Execution of Thermit Welds	Improvement of control and techniques of thermit welding	Ultrasonic Rail Inspection, X Rays, Gamma graphics	
Ballast	Ballast Wear	Vehicle-Track Interaction		Ballast Grain Size Tests	
	Ballast Pollution	Unfavourable Environment Conditions			
		Pollution during picking up and transport	Intensive Care on Ballast Processes		
Sleepers	Cracks on Monoblock Concrete Sleepers	Alkali-stone expansive reaction	Adequate Proportions on Mixing Components	Tests in manufacturing plants, New digital images processing techniques based on continuous image	
		Problems during Manufacturing Process	Intensive control on Manufacturing Plants		
	Open Gauge Problems on Twin Block Concrete Sleepers	Progressive Bending of metallic joint between blocks due to amount of traffic		Track Geometry Inspection	

ADIF - INNOTRACK IM WORKSHOP - PHASE 1 (4 of 5)

Components	Symptoms	Causes	Possible Solutions	Evaluation Methods	Other Comments
Substructure	Track alignment defects	Earth pressure	Slopes or unstable batters stabilization by means of rigid structures (walls, shear walls), drainage improvements, etc.	Movements detection by means of instrumentation or using the track inspection coach	
		Platform instability	Platform or embankment stabilization		
	Track levelling defects	Platform instability (collapse, landslide, et	Platform treatment by means of the improvement of its stiffness (grouting, materials replacement, geotextile, etc) or by means of its consolidation with structures (walls, shear walls, etc)		
		Deficient drainage state	Improvement of the drainage system, responsible for track instability derived from water or mud accumulations		

ADIF - INNOTRACK IM WORKSHOP - PHASE 1 (5 of 5)					
Components	**Symptoms**	**Causes**	**Possible Solutions**	**Evaluation Methods**	**Other Comments**
Drainage	Water accumulations in the track ditch	Ditch siltation caused by landslides	Talus treatments to avoid material falling into the ditches	Visual detection	
		Ditch siltation caused by deposit of transported solids	Installation of sand boxes		
		Insufficient gradient for water flows	Reconstruction of the longitudinal drainage in order to improve the water flow		
	Water accumulations in stream beds next to the track	Non-existence of cross drainage	Building of cross-sectional pipes to the track, in order to allow water to flow		
		Land accumulation due to soil erosion, which makes it difficult for water to	Periodic cleaning of the drainage systems		
		Flow through the drainage			
		Insufficient gradient for water flows due to a bad construction	Building of a new pipe, adequate to the water flows		
	Sapping due to the water flows on the platform	Inadequate design of the drainage system for the existent water flows	Reconstruction of the drainage for the existent water flows		
Fasteners	Loose Elastic Fasteners	Bad control on torque applied to adjust fasteners, conducing to inapprpiate vertical clamping force	Extensive use of dynamometric keys and other devices of torque control	Track Geometry Inspection and Sample Tests on Torques and Vertical Forces Applied from Plain Line	
Joints	Insulated Joints affecting Track Circuits' normal operation	Breakage or fragility conducing to interrupt track circuits	Redesign of insulated track joints or adaptations of track circuits' frequency		
	Irregularities on Jointed Track	Vehicle-Track Interaction	Progressive introduction of continuous welded rail during rail renewals		

Figure 2 - Results of ADIF IM Workshop Phase 1 (1 to 5)

7.3 Annex C: RFF IM Workshop - Phase 1 Results

Results from the brainstorming about major cost drivers in the track					
Comp-onent	**Symptoms**	**Causes**	**Possible solutions**	**Evaluation methods**	**Comment**
Switches & Crossings	Replacement of half points (switches)	wear			Impact on maintenance cost: 1 (very high)
	Mono-block hearts	wear			Impact on maintenance cost: 1 (very high)
Track	Replacement and renewal of rails	Internal default (head checking, squat or metal fatigue)	One problem is that the ultrasonic inspection is too slow: 50kph max, If faster, the signal is lost, Any technical solution that would allow faster US inspection would help lower maintenance cost of rail,	Ultrasonic inspection	Impact on maintenance cost: 2 (high)
Joints	Replacement and inspection	Creation of an electrical bridge over by metallic particules			Impact on maintenance cost: 1 (very high), also impact on safety since it can alter train detection system
Ballast	Ballast flying	High speed (above 300kph)	Would it be possible to investigate the possibility of recycling ballast ?		Major cost impact on high speed line
Sleepers	Corrugation of twin block sleepers	Inappropriate protection, poor quality of steel or wrong design (a brace of 6mm is too thin)			Impact on maintenance cost: 1 (very high)

Figure 3 - Results of RFF IM Workshop Phase 1

7.4 Annex D: BV IM Workshop - Phase 1 Results

Comp-onent	Symptoms	Causes	Possible solutions	Evaluation methods	Comment
Switches & Crossings	Tounge/blade not in position	Snow/Ice drops from vehicles	De-icing more often	Service Statistics	Common problem in South regions
	Cracks in Manganese crossings	High axel loads/high speeds, inadequate maintenance after installation	Welding. New maintenance instructions	Visual inspection	
	Wear in switches	Bad track geometry in front of the switch	New ideas for condition monitoring, individual switch maintenance programs	Manual inspection	Use degradation curves. Increase condition monitoring without reducing safety
		Wheel condition	Better follow-up and condition monitoring of wheels. Operators update their maintenance strategies/methods		Differentiated track access charges are an incitament for better maintenance & design
		Bogie design	Redesign		
		Sub-structure	More frequent maintenance intervals, drainage		
Track	Bad track geometry	Frost heaving			Difficulties to use track geometry data from inspection car
		Soft sub-structure			
		High vehicle forces		Simulation of vehicle behaviour	
		Track not put into designed position	Maintenance of the reference positions		
		Wrong/unknown stress-free temperature	neutralise		
		Bogie suspension bottoming out	Vehicle maintenance/redesign		
Joints	Shortcut in isolation joints	Metal flaws, plastic deformation	Frequency track circuits		

Comp-onent	Symptoms	Causes	Possible solutions	Evaluation methods	Comment
Rail	Wear	Lack of lubrication	Add lubrication		New maintenance limits
		Wheel/rail profile not adequate	Revised maintenance limits		
		Narrow curves	Add lubrication, other steel types		
	Corrugation	High unsprunged wheel mass			
		Spinning wheel	Traction control, sanding		
	Low friction/traction	Leaf fall into track	Tree cutting, sanding, water cleaning		
	Cracks, Fatique	Wheel flats, Worn wheels		Ultrasonic detection methods, new inspection routines	
		Too low wear	Grinding		
		Bad wheel/rail interface	Profile optimisation		
Sub-structure	Unstable	Soft sub-structure, wet bed	Reinforcement, drainage, ditching, frost isolation, excavation		
Ballast	Stone spray	Ice clumps drops from vehicles	De-icing vehicles, ballast plowing		Winter problem
Culvert/pipes	Collapsed	High axle load			
	Flooding	Culverts/pipes plugged with dirt			
Sleepers	Difficulties to decide when to replace	Rutten wood	New criterias for replacement		
Fasteners	Worn/missing pads	Dynamic forces from trains	Optimisation		FIST-type fasteners gets broken
Infrastructure in general	Failures/Traffic disturbances/High costs	Maintence strategy poor/missing	More preventing and predictive maintenance including condition monitoring and trending		Approval of new technology takes too long. A common standard in Europe might help
			Use monitor data for long-term planning		
			New methods		
		Climate: snow, ice, rain, heat, sun-related failures			
Vehicles	Cargo dropped	Leaking/Open cars	Fixing of load, Maximum load height, Penalties, Monitoring of loading gauge		

Figure 4 - Results of BV IM Workshop Phase 1 (2 of 2)

7.5 Annex E: DB IM Workshop - Phase 1 Results

Rails

Nr.	Fragestellung - Problem	Relevanz - Importance	Ursachen - Underlying cause	Randbedingungen - Boundary conditions	Lösungen - Solutions
		W/B			
					Fahrflächenfehler: Schädigungstiefe, IH-Maßnahmen - Running surface faults: Damage depth, maintenance measures
1	Oberflächennahe Fehler HEADCHECKS	4 / 4	Kontaktkräfte bei Schlupf - Creep forces	Antrieb mit modernen Fahrzeugen - Modern traction systems	Einflußfaktoren: Belastung, Fahrzeuge - BR; Wechselwirkung Rad-Schiene - Influencing factors: Load, vehicles - BR(?), wheel/rail interaction
			Radgüte - wheel performance	Drehgestell (ICE) - ICE bogies	
			Rad/Schiene Profile - Wheel/rail profile	überwiegend im Bogen, unabhängig vom Radius - Predominantly in curves, independent of radius	Grenzwerte für Radprofilverschleiß? - Threshold for wheel profile wear
			Kopfform des Schienenkopfes relevant? - Is profile of the rail head relevant?		Optimierung Rad/Schiene Profils - Optimisation of wheel/rail profiles
			Ist die UIC 60 die richtige S-Form für unsere Ansprüche? - Is UIC 60 the correct rail profile for our requirements?		Einfluß Bogen auf Schienenfehler (Schleifprogramm) - Influence of curves on track defects (Sliding programme)
					Optimierung Stahlgüte (Fragestellung 3x) - Optimisation of steel grade (Problem 3x)
					Entwicklung oberflächennahe Si-Fehler vs. maschinelle Si-Bearbeitung - Development of failures versus machine grinding
					Bezug/Korrelation Schienenfehler-Belastung-IH? - Correlation between rail defects - Load - maintenance

Nr.	Fragestellung - Problem	Relevanz - Importance	Ursachen - Underlying cause	Randbedingungen - Boundary conditions	Lösungen - Solutions	Rechtzeitige Fehlererkennung Systeme?	Strecke - Route
2	Schienenfehler Belgrospie, Anwendung Ro 7/2006 - Rail defects Belgrospie	2 / 4	Schienenriffeln ! - Corrugations	v>200 km/h; gerades Gleis - straight track	rechtzeitige Beseitigung von Headchecks(?) - Riffeln - prompt removal of headchecks - short pitch corrugations		M230 Strecke 1733
3	SQUATS	4 / 4	RCF	gerades Gleis - straight track geringer Verschleiß - lower wear			M160 / G120 Streckenkette: 5200, 5321, 5310, 5300, 5302
4	Seitenverschleiß - Flange wear	3 / 1			Einsatz hochfester Schienen ab welchen Radien? - Adoption of high-fixity rails for which radii?		
5	Reduzierung von Sperrzeiten bei Schweißung? - Reduced line closures using welding?						
6	Schlupfwellen im Bogen - Long pitch corrugations in curves	2 /1		R<800m	Optimierung Gleiselastizität - Optimisation of track elasticity		
7	Schienenriffeln	2 /1		Trassierung - alignment Drehgestellkonstruktion - bogie construction			

Switches and Crossings

Nr.	Fragestellung	Relevanz	Ursachen	Randbedingungen	Lösungen	Strecke
1	Herzstück-Verschleiß - Common crossing wear Verschleiß Herzstück: Verformung, oberflächennahe Fehler - Common crossing wear: Deformation, head checks Verschleißentwicklung am Herz: Welche Stahlgüte ist erforderlich? - Wear development on common crossings: which steel grade is necessary? Herzstückkonstruktion-Blockherzstück Schweißeignung - Common crossing construction - Cast crossing weld acceptability	4 / 4	Herzstückkonstruktion Radsatzprofil (Hohllauf) - Crossing construction, wheel set profile (concave running?)		Grenzwerte für Radprofile Optimierung Materialgüte, Geometrie und Konstruktion - Threshold for wheel profile optimisation, material grade, geometry and construction	Herzstückversuchs-strecke - Common crossing test track Haste - ???
2	Wärmeführung bei Auftragsschweißung - Heat conduction in built-up welds	3 / 1			Qualitätssicherung - quality assurance	

Nr.	Fragestellung	Relevanz	Ursachen	Randbedingungen	Lösungen	Strecke
3	Optimale Instandhaltung? (Wie, Wann, Was?) - Optimum maintenance? (How, when, what?)	3 / 1			Detaillierung notwendig! - detail essential	
4	Horizontaler Verschleiß in der Zungenvorrichtung (ZV) RL bzw. LR - horizontal wear in a switch blade mechanism: right to left, or left to right	3 / 2		kleiner Halbmesser <=500m - smaller radius (less than 500m)	Backenschiene + ZGV Volumenvergütung generell? - ???	
					Einsatz vergüteter Großteile - Sinnhaftgkeit? - Use tempered components - significance?	
5	Zungenbruch Zungenausbruch - switch blade crack; switch blade break	1 / 1			Witec-Zungen immer und überall? - Always use Witec blades	
6	Headcheck auf Zungen - Head checks on switch blades	siehe Schiene				
7	Auf welcher Geschwindigkeit sollen wir bewegliche Hz einbauen? - At whar speed should we intall flexible timbers?	1 / 1		Trassierung Drehgestellkonstruktion - track bed; bogie construction		

Drives and Locking Devices

Nr.	Fragestellung	z	Ursachen	Randbedingungen	Lösungen	Strecke
1	Kopplung Stellwerk zu Antrieb - Connection of control centre to drive	4/1	herstellerspezifische Schnittstellen - Manufacturer specified interfaces	Migration neuer Systeme - Migration to a newer system	Offene Schnittstelle zum Stellsystem - Excellent interfaces with the control system	
2	Inspektionsfristen Oberbau-LST - Inspection period	4/1	unterschiedliche Fristen für Oberbau und LST - Various periods for superstructure and LST		Harmonisierung, Optimierung Prozess - Harmonised and optimised control process	
3	Energie Weichenheizung - Energuy for point heating	4/2	Hohe Energiekosten für Weichenheizung - High energy costs for point heating	Winter, tiefe Temperaturen, große Radien - Winter, low temperatures, large radii	Optimierung der Weichenheizung, andere Energiequellen, Isolierung Optimisation of point heating, alternative energy sources, insulation	Erprobung Erdwärme - Holzminden - Check out ground heating - ???
4	Überwachungssystem Endlagenprüfung - Point-end detection system	3/4	Ja-Nein Aussage - Yes-no answer		Überwachung der Endlage durch Abstandsmessung, Dokumentation der Entwicklung der Fehler - End detection through gap measurement, documentation of development of faults	1733
5	Anforderungen an den Weichenantrieb, Stell- und Überwachungssystem - Specification of the point drive, control and monitoring system	3/3	hohe Instandhaltungsaufwendungen - high maintenance expenditure		Lastenheft - Specification	
6	Anforderung an Monitoringsysteme - Specification of the monitoring system	3/3	Kein Standard, keine Vorgaben für zu monitorende Werte -, No standards, no parameters for the monitored values	hochbelastete Strecken - Heavily used routes	Standardisierte Monitoringsysteme - Standardised monitoring system	Erprobungsabschnitt Monitoingsysteme B-Mü-FFM (Stadtbahn, S-Bahn, ??), Heidenheim - Investigation area - existing interface monitoing systems
7	Schmierung der Weiche - Lubrication of the switch Klammerverschlüsse - Clamp lock Gleitstühle - Slide chair Auszugsspitzen - ???	4/3	Kurze Standzeiten und unzureichende Eignung für alle spez. Anwendungsgebiete - short service life and inapplicability for all specialised application areas	hohe Belastung, hohe Umstellhäufigkeit - Heavy use, frequent switch operation	Optimierung der Schmiermittel zur Erhöhung der Standzeiten - Optimisation of the lubricant to extend the service life	Erprobungsabschnitte - Schmierung - Investigation area - Lubrication

Ballast

Nr.	Fragestellung	Relevanz	Ursachen	Randbedingungen	Lösungen	Strecke
1	Qualitätsnachweis BR (2x) - Quality assurance	3 / 2		Witterungsabhängigkeit - Weather dependency	praktikable witterungsunabhängige Qualitätssicherung - Kennwerte - Feasible weather-independent quality assurance - characteristics	
	Wirtschaftlichkeit Bettungsreinigung - Cost effective ballast cleaning					
	Kontrollierte Schotterreinigung mit BRM - Controlled ballast cleaning with BRM				Entscheidungs-grundlage für BR - Decision basis for BR	
	Bettungsreinigung auf SFS - Ballast cleaning with SFS				Wie machen es andere Bahnen? - How do other railways do it?	
2	Bettungsquerschnitt - Ballast layer cross-section	2 / 3			Tolleranzbereich? - Available tolerance?	
	Schotterfunktion im Gleis - Ballast function in track					
3	Bettungsdicke - Ballast layer thickness	3 / 1			Optimierung - Optimisation	1733, M160, G120
	Sieblinie/Körnung - Particle size distibution curve / Granularity					1733, M160, G120
4	Anforderungen an RC-Schotter - RC ballast requirements	1 / 1			Einsatz Rc-Schotter bei anderen Bahnen? - Adoption of ??? Ballast by other railways?	
5	Einzelfehler/Linienbaustelle DUA? - 'Spot' defects / Track works DUA	3 / 3			Erfahrungen andere Bahnen? IH-Konzepte, Logistik - Experience of other railways? Maintenance concepts, Logistics	
	Schichtleistung [m]? - ????					
6	Einsatz DGS? - Adoption of	2 / 2				

Drainage

Nr.	Fragestellung	Relevanz	Ursachen	Randbedingungen	Lösungen
1	Ursachen der Gleislageveränderung > Unterbau-Entwässerung - Cause of track bed changes > Sub grade drainage	4 / 3			Finanzierung bei anderen Bahnen? - How do other railways pay for this?
2	Schlammstellen - Ingress of silt	2 / 2	Zerstörung der Filterstabilität durch Umbau - Destruction of the drainage filters during subsequent works		
3	Forderung an Entwässerunganlagen festlegen - Establishing the requirement for drainage equipment	4 / 3			Entwässerungs-konzepte - Drainage concepts
	Folgen aus Versagen von Entwässerung und Unterbau - Consequences of failure of drainage and sub-grade				Wie machen es die anderen Bahnen? - How do ther railways do it?
	IH Tiefenentwässerungen und Vorfluter - Maintenance of deep drainage and receiving water courses				
4	fehlende Flankenreinigung	2 / 2			sinnvolle Konzepte bei anderen Bahnen? - Feasible concepts from other railways
	Veränderung unserer alten Dämme - Changes to our old dams				
	Gleiserneuerung ohne UVV - Track renewal without UVV				genereller Umbau mit PSS?
5	Einsatz Analyseverfahren z.B. Georadar - Adoption of analysis procedures; for example, ground penetrating radar	3 / 2	Inhomogenität - Varying sub-grade		
	Tragfähigkeitsnachweis Bodengutachtentrag - Bearing capacity				
6	Ertüchtigung (was, Methode)? - Strengthening (What, Method)?				

System

Nr.	Fragestellung	Relevanz	Ursachen	Randbedingungen	Lösungen	Strecke
1	Präventives Schleifen - Preventative grinding	geh. zur Schiene				1733
2	Analyse der Inspektionsergebnisse - Analysis of inspection results				Wie machen es die anderen Bahnen? - How do other railways do it?	
3	Kombination von IH-Prozessen z.B. DUA und Schleifen - Combination of Maintenance processes; for example, DUA and grinding	3/3				
4	Vegetationskontrolle präventiv oder zustandsbezogen	2/1			chemische Bekämpfung Intervalle - Chemical control interval	
5	Inspektionsumfang Inspektionskonzepte Eingriffsschwellen für Instandhaltung - Inspection area, inspection concept, intervention thresholds for maintenance	4/1			Wie machen es die anderen Bahnen? - How do other railways do it?	Streckenkategorien - Route categories
6	Gültigkeit / Eignung von Messverfahren (z.B. bei Schienenprüfung) - Validity / acceptability of measurement procedures (eg rail testing)				Wie machen es die anderen Bahnen? - How do other railways do it?	

Figure 5 - Results of DB IM Workshop Phase 1 (8 of 8)

7.6 Annex F: ProRail IM Workshop - Phase 1 Results

Comp-onent	Symptoms	Causes	Possible solutions	Evaluation methods	Comment
Switches & Crossings	RCF- Head Checks	High contact stresses between wheel and rail resulting in high levels of plastic deformation in combination with insufficient wear to remove crack initiation.	Optimised railmaterial in terms of grade and/ or rail head profile. A second solution is the introduction of a RCF grinding strategy.	Laboratory tests combined with Field tests.	ProRail has investigated in this area over the last years and can offer a lot of valuable data.
	RCF- Squats	Geometric disturbances at the rail head leading to growing impact forces, resulting in material overload and crack formation and growth.	Frequent Grinding, optimising rail support	International Experiences (Japan), Field tests.	
Track	Track geometry degradation	The influence of local track geometry disturbances is to be seen when inspecting the rail infrastructure. The vehicle response to local disturbances is of strong influence to the appearing track damage. Increased track loading (intoduction of new 'stiff' boogie designs and 'unforgiving' stiffer track) in combination with new and optimised track monitoring systems present respectively the need and opportunity to review track maintenance standards and techniques.	ProRail uses a tool called Pupil to assess the quality of the track geometry. This tool is based on Dutch vehicle models and is also used to develop new rules of thumb. How do other IM's assess the geometry? Is a dedicated Pupil also useful for other countries?	Analysis of track degradation (statistically, from observations - monitoring programs).	
	Insufficient quality of track maintenance negatively influencing track capacity	To evaluate the quality assurance of track maintenance accepted generic methods are lacking.	Investigate approaches to assure that carried out maintenance activities result in the demanded track quality in conformity with the set agreements (safety, maintenance standards).		
Joints	Track welding quality assurance	ProRail recognises that efforts have to be taken to bring rail welding (including repair welding) on a high and consisted level.	Share experiences and develop together a best practice for the moost common rail grades: instructions, welding specifications, ongoing research and development programs etc.	Laboratory testing and field testing.	

Comp-onent	Symptoms	Causes	Possible solutions	Evaluation methods	Comment
Rail	RCF- Head Checks	High contact stresses between wheel and rail in curves (especially moderate curveradius 750 m < r < 3000 m). Resulting in high levels of plastic deformation in combination with insufficient wear to remove crack initiation.	Optimised railmaterial in terms of grade (increased resistance against plastic deformation and crack growth) together with optimised rail production technique (influence residual stresses). A second solution is the introduction of optimised rail head profile in combination with a RCF grinding strategy.	Laboratory tests combined with Field tests.	ProRail has investigated in this area over the last years and can offer a lot of valuable data.A Head Check retarding rail grade has been introduced succesfully.
	RCF- Squats	Geometric disturbances at the rail head leading to growing impact forces, resulting in material overload and crack formation and growth.	Frequent Grinding, optimising rail support	International Experiences (Japan), Field tests.	After ProRail having successfully reduced and stabilized Head Check damage in the main line, now the Squat issue is demanding more attention.
	Controlling Crack development in the rail head	Cracks in the rail head have to be identified in a early stage in order to grind them out. It can however be expected that occasionally cracks will 'escape' from the grinding point of view because they will have grown too deep before noticed. These sections will have to be replaced at a later date. It is known that, when no action is taken, cracks will grow towards to the foot of the rail and eventually can cause a rail break. High internal tensile stresses resulting from rail straightening operation during rail production negatively influence crack retarding properties of the rail material.	There is evidence that crack development in a rail head can be controlled and influenced in a positive way from safety point of view with alternative production techniques avoiding high tensile residual stresses. This would provide a extra safety precaution from which the whole system would benefit strongly (less panic, less cost).	laboratory tests combined with Field tests.	
	Rail Corrugation				
Sub-structure					
Ballast					
Culvert/pipes					
Sleepers	Rail on Concrete sleepers is more susceptible to RCF damage.	Stiff construction leading to increased peak contact stresses.	Softer pads, sleeper design changes.	laboratory tests	
Fasteners					

Component	Symptoms	Causes	Possible solutions	Evaluation methods	Comment
Infrastructure in general	Crack detection	ProRail currently relies on visual inspection regarding RCF crack detection. This is a very time consuming and non-objective approach. Therefore there is need for an automated inspection tool. ProRail is introducing a train based system using the Eddy current technique. How do the SP1 members deal with crack detection.	ProRail is introducing a train based system using the Eddy current technique. How do the SP1 members deal with crack detection.	Validation in the Field.	
	Crack depth measurement - do we replace rail too early?	ProRail currently uses standard ultrasonic technique to measure crack depth in rail. The validation of this technique shows the technique to be very conservative. This means that a lot of rail is being classified wrongly (unnecessary claiming maintenance capacity) and unnecessary / too early replaced. There is need to bring new techniques into the track, (TOFD is currently under investigation at ProRail).	A new NDT technique, based on ultrasonics, is currently under investigation at ProRail.	Validation in Field.	
	Railway Noise	Rolling Noise; rail/ wheel corrugation. Squeal; Lateral slip between wheel and rail.	ProRail has been focussing on Railway Noise very strongly over the last years through the National noise reduction program IPG. Especially the problem of Squeal Noise at stations is a big environmental problem. Measures could be investigated by the SP1 partners.	InfraStructure Experiences.	
	Tonnes of data but no information..	There is a lack on structure in data acquisition and processing. Fragmentation is leading to incomplete and contradicting output.	Need to development data acquisition rules, analysis techniques and presentation formats.	Benchmark	
Vehicles	Development of a vehicle classification system	New vehicles are designed for optimum ride quality, disregarding the forces it puts to the track.	Venicle design should incorporate track loading / contact stresses. Most Dutch trains have been modelled over the years in ADAMS/Rail and Simpack and that knowledge can be used for development of generic vehicle models.	Possibly combining this with train assessment; measurement of steering forces to tune models, especially wheel/rail interaction / friction curves etc	

Figure 6 - Results of ProRail IM Workshop Phase 1 (3 of 3)

7.7 Annex G: ÖBB IM Workshop - Phase 1 Results

Track Problems

1. Drainage
2. Ballast quality
3. Ballast damage arising from poor track maintenance
4. Grinding requirements
5. Poor sub-grade quality
6. Maintenance of track design geometry
7. Maintenance of sub-grade stiffness
8. Damage from high track forces
9. Switch wear

7.8 Annex H: NR IM Workshop - Phase 1 Results

Specific Cost Drivers

- Inspection – visual
- Inspection – train based (geometry, ultrasonic, eddy current, visual, etc.)
- Track geometry maintenance
- Reliability of switch diamonds
- S&C geometry maintenance
- Curve geometry maintenance (predictive inspections)
- Measurement of geometry
- Embankments and structures
- Management of stress in rails (measurement) particularly at S&C, structures, etc.
- Maintaining existing S&C
- Wet beds
- Dynamic track stabilisation
- Lack of tools to identify root causes and reoccurring problems
- Weld repair technology and strategy (speed, reliability)
- Stressing of rails during welding
- Cost of complying with European TSIs (e.g. noise, new build requirements)
- Joint design and maintenance (supported vs. insulated)
- Lubrication of plain track and S&C (understanding LCC issue and optimisation) – noise, wheel wear, etc.
- Management of wheelset defects (monitoring, wheel profile management)
- Level crossing track maintenance and design (geometry)
- Rail foot corrosion and coatings
- Rail pad design and renewal
- Rail foot stresses (management and reduction)
- Top of rail friction control both rail and wheel based (leaf fall, management of damage)
- Ballast out of specification prior to installation (logistics, quality control)
- Timber quality and preservation

Potential New Solutions

- Under sleeper pads to reduce tamping requirements
- Remote monitoring (S&C, etc.)
- Drainage maintenance and installation (identification of drainage issues)
- New tools for the prediction of the impact of fleets on routes (maintenance and renewals)
- Limiting access to heavy axle vehicles on fragile routes (allocated freight routes, cost implications of usage)
- Innovate rail defect removal

Requirements for New Solutions

- Asset renewal/maintenance decision making
- Life extension of track
- Improved understanding and management of defects

- Tamping decisions (complexity/efficiency)
- Rural railways (community railway) standards
- First cost (and construction approach) of slab track
- Recycling materials (rail)
- Quality of track installation (right quality first time)
    - Straight track
    - Curved track
- Quality of maintenance (focussing of maintenance at high risk locations)
- Possession and isolation management (time to setup, cost of safety rules)
- Improved utilisation of track renewal, maintenance, labour and plant
- Improved effectiveness (competency) of work force (problem solving)
- Supporting tools (and data) to help decision making
- Improved work force skills
- Improved quality and telescoping of track renewals planning
- More mechanisation of processes
- Understanding optimal (acceptable) levels (KPIs, cost drivers) – e.g. rail breaks, TSRs
- Formation renewal strategy
- Understanding LCC of stiffness and drainage
- More rapid re-railing (particularly short sections with defects)
- Benefits available from track friendly vehicles
- Strategy for track design and maintenance for track unfriendly vehicles
- Grinding strategy (optimisation of LCC) – rail hardness, route specific
- Locations for different rail grade usage
- Assessment of minimum action for defects
- Understanding the relationship between defect growth and duty conditions
- Is there a need to inspect new rail that is obviously defect free?
- Sleeper selection based on duty, wear, track quality (plastic sleepers)
- Appropriate sleeper spacing given duty and rail weight
- Efficiency of usage of work force
- Rail fastening characteristics

7.9 Annex J: Consolidated Results from IM Workshop Phase 1

Innotrack: SP1 - Summary of Results from National Infrastructure Managers' Workshops

Component	Problems	Extent of Problem								Countries Reporting Problem							
		12%	25%	37%	50%	62%	75%	87%	100%	E	F	S	CZ	D	NL	A	UK
Switches and Crossings	Point 'detection' problems	■	■									■		■			
	Maintenance of geometry	■	■											■			■
	Reliability of switch diamonds	■															■
	Cracks in cast manganese crossings	■	■									■		■			
	Wear in switches	■	■	■	■	■	■				■	■		■	■	■	■
	Switch blade failure	■												■			
	Failure of stock rail	■								■							
	Failure of common crossings	■	■							■	■						
	Wear of common crossings	■												■			
	Reduction of gauge	■								■							
	Control failures	■												■			
	High energy demand for point heating	■												■			
	Failure to optimise switch system	■												■			
	Frequent lubrication of switches	■												■			

Innotrack: SP1 - Summary of Results from National Infrastructure Managers' Workshops

Component	Problems	Extent of Problem								Countries Reporting Problem							
		12%	25%	37%	50%	62%	75%	87%	100%	E	F	S	CZ	D	NL	A	UK
Track	Bad track geometry	■	■	■	■	■	■			■		■		■	■	■	■
	Reduced line speeds after maintenance work	■															■
	Limited access for inspection	■															■
	Noise	■													■		
	Quality assurance	■													■		

Innotrack: SP1 - Summary of Results from National Infrastructure Managers' Workshops

Component	Problems	Extent of Problem								Countries Reporting Problem							
		12%	25%	37%	50%	62%	75%	87%	100%	E	F	S	CZ	D	NL	A	UK
Joints	Electrical shorting in isolation joints	■	■	■	■					■	■	■					■
	Stressing rails during welding	■															■
	Weld quality	■	■							■							■
	Fishplate failure on monoblock crossings	■								■							
Rail	Wear	■	■	■						■		■					■
	Flange wear	■												■			
	Corrugation	■	■	■						■		■		■			
	Low friction/traction	■	■									■					■
	Cracks, Fatigue	■	■	■	■	■	■			■	■	■		■	■		■
	Residual stresses	■															■
	Corrosion	■															■
Sub-structure	Unstable	■	■	■	■	■				■		■		■		■	■
Ballast	Stone spray	■	■								■	■					
	Quality assurance of material	■												■			
	Optimisation of ballast layer function	■												■			
	Optimised treatment of spot defects	■												■			
	Silt ingress	■												■			
	Cost effective ballast cleaning	■												■			
	Ballast wear	■	■							■						■	
Culvert/pipes	Collapsed	■										■					
	Flooding	■	■							■		■					
Sleepers	Difficulties to decide when to replace	■	■									■					■
	Cracked concrete monoblock sleepers	■	■							■	■						
	Gauge spread with twin block concrete sleepers	■								■							
Fasteners	Worn/missing pads	■	■									■					■
	Loose fasteners	■								■							
Structures (bridges and embankments)	Failures/Traffic disturbances/High costs	■	■									■					■
Vehicles	Cargo dropped	■										■					
General	Vegetation control	■												■			
	TSI compliance	■															■

Figure 7 - Consolidated Results from IM Workshop Phase 1

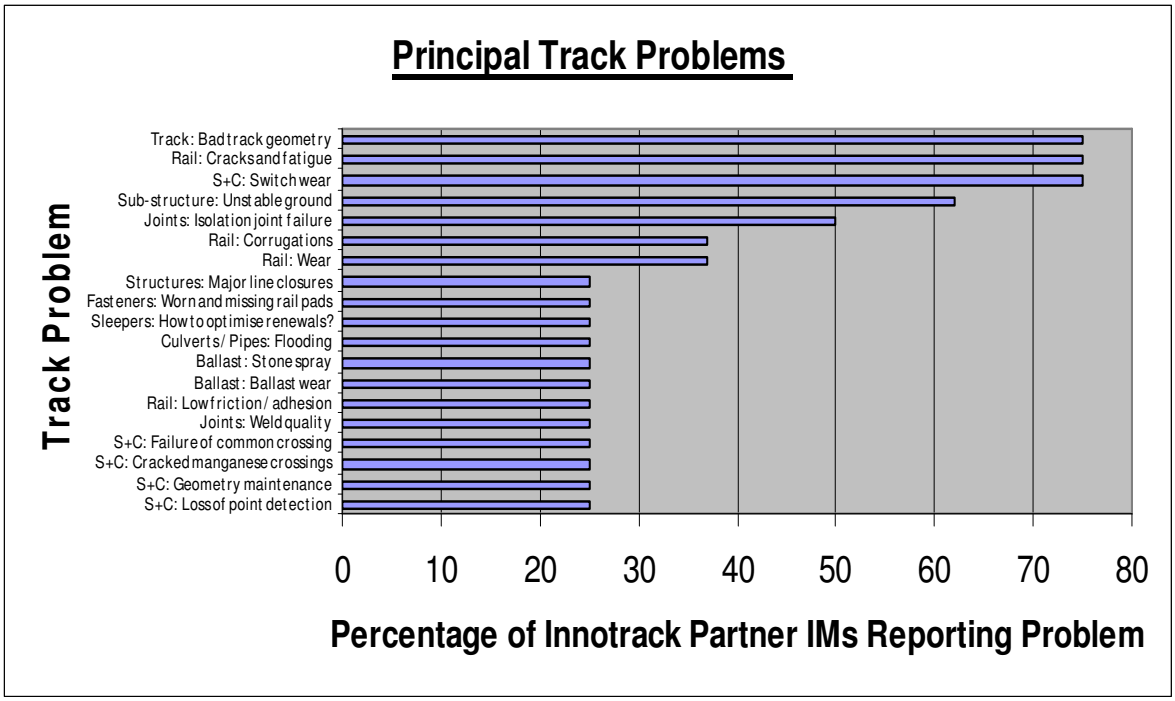


Figure 8 - Histogram Showing the Principal Track Problems Identified by the IM Workshops Phase 1

7.10 Annex K: Track Problem Prioritisation Template – IM Workshops Phase 2

Innotrack: SP1 - Summary of Results from National Infrastructure Managers' Workshops

Component	Problems	Suggested Causes	Extent of Problem								Countries Reporting Problem								Priority Rating				
			12%	25%	37%	50%	62%	75%	87%	100%	ADIF	RFF	BV	CD	DB	PR	OeBB	NR	1	2	3	4	5
Switches and Crossings	Tongue/blade not in position	Snow/ice drops from vehicle																					
	Maintenance of geometry																						
	Reliability of switch diamonds																						
	Cracks in manganese crossing	High axle loads/high speeds/inadequate maintenance after installation																					
	Wear in switches	Bad track geometry in front of the switch																					
		Wheel condition																					
		Bogie design																					
		Sub-optimal rail lubrication																					
		Sub-structure																					
	RCF in switches																						
	Failure of stock rail	Initial crack in fillet radius																					
	Wear and failure of common crossings	High fatigue load due to loss of geometry																					
	Reduction of gauge	Crushing of rail head																					
		Crushing of crossing nose																					

Innotrack: SP1 - Summary of Results from National Infrastructure Managers' Workshops

Component	Problems	Suggested Causes	Extent of Problem								Countries Reporting Problem								Priority Rating				
			12%	25%	37%	50%	62%	75%	87%	100%	ADIF	RFF	BV	CD	DB	PR	OeBB	NR	1	2	3	4	5
Track	Bad track geometry	Frost heaving																					
		Soft sub-structure																					
		High vehicle forces																					
		Track not in designed position																					
		Sub-optimal maintenance																					
		Wrong/unknown stress-free temperature																					
		Bogie suspension bottoming out																					
		Inadequate management of wheel set defects																					
		Poor fault prediction																					
		Rail pad design and renewal																					
		Ballast does not meet design specification																					
		Inadequate design and maintenance of level crossings																					
	Reduced line speeds after maintenance work																						
	Limited access for inspection																						
	Noise																						
	Quality assurance																						

Innotrack: SP1 - Summary of Results from National Infrastructure Managers' Workshops

Component	Problems	Suggested Causes	Extent of Problem								Countries Reporting Problem								Priority Rating				
			12%	25%	37%	50%	62%	75%	87%	100%	ADIF	RFF	BV	CD	DB	PR	OeBB	NR	1	2	3	4	5
Joints	Electrical shorting in isolation joints	Metal flaws, plastic deformation	■	■	■						■		■					■					
	Stressing rails during welding		■															■					
	Weld quality		■	■							■							■					
	Fishplate failure on monoblock crossings	Insufficient support at joint	■								■												
Rail	Wear	Lack of lubrication	■	■									■					■					
		Wheel/rail profile not correct	■	■									■					■					
		Tight curves	■										■										
		Incorrect rail inclination	■								■												
	Corrugation	High unsprung wheel mass	■										■										
		Spinning wheel	■										■										
		Vehicle / track interaction	■								■												
		Wheel flats and/or oval wheels	■								■												
	Low friction/traction	Leaf fall into track	■	■									■					■					
	Cracks, Fatigue	High dynamic forces (eg wheel flats)	■	■									■					■					
		Low wear resulting in crack growth	■										■										
		Residual stresses after straightening	■													■							
		Bad wheel/rail interface	■	■	■	■					■		■			■		■					
		Inclusions in rail steel	■								■												
		Incorrect stress free temperature	■								■												
	Squats	Wheel slip	■	■							■					■							
	Residual stresses		■															■					
	Corrosion		■															■					

Innotrack: SP1 - Summary of Results from National Infrastructure Managers' Workshops

Component	Problems	Suggested Causes	Extent of Problem								Countries Reporting Problem								Priority Rating				
			12%	25%	37%	50%	62%	75%	87%	100%	ADIF	RFF	BV	CD	DB	PR	OeBB	NR	1	2	3	4	5
Sub-structure	Unstable	Soft sub-structure, wet bed	■	■	■	■					■		■				■	■					
Ballast	Stone spray	Ice clumps drops from vehicles	■										■										
	Ballast wear	Vehicle / track interaction	■	■							■						■						
Culvert/pipes	Collapsed	High axle load	■										■										
	Flooding	Culverts/pipes plugged with dirt	■	■							■		■										
Sleepers	Difficulties to decide when to replace	Rotten wood	■	■									■					■					
	Cracked concrete monoblock sleepers	Alkali-silica reaction	■								■												
		Manufacturing problems	■								■												
	Gauge spread with twin block concrete sleepers	Failure of steel tie between blocks	■								■												
Fasteners	Worn/missing pads	Dynamic forces from trains	■	■									■					■					
	Loose fasteners	Incorrect torque	■								■												
Structures (bridges and embankments)	Failures/Traffic disturbances/High costs	Maintence strategy poor/missing	■	■									■					■					
		Climate: snow, ice, rain, heat, sun-related failures	■	■									■					■					
Vehicles	Cargo dropped	Leaking/Open cars	■										■										
General	Cost of complying with TSIs		■															■					

Figure 9 - Template used in the Prioritisation of Track Problems

7.11 Annex L: ADIF IM Workshop – Phase 2 Results

Innotrack: SP1 - Summary of Results from National Infrastructure Managers' Workshops

Component	Problems	Suggested Causes	Extent of Problem								Countries Reporting Problem								Priority Rating				
			12%	25%	37%	50%	62%	75%	87%	100%	ADIF	RFF	BV	CD	DB	PR	OeBB	NR	1	2	3	4	5
Switches and Crossings	Tongue/blade not in position	Snow/ice drops from vehicle																					
	Maintenance of geometry																						
	Reliability of switch diamonds																						
	Cracks in manganese crossing	High axle loads/high speeds/inadequate maintenance after installation																					
	Wear in switches	Bad track geometry in front of the switch																					
		Wheel condition																					
		Bogie design																					
		Sub-optimal rail lubrication																					
		Sub-structure																					
	RCF in switches																						
	Failure of stock rail	Initial crack in fillet radius																					
	Wear and failure of built-up common crossings	High fatigue load due to loss of geometry																					
	Reduction of gauge	Crushing of rail head																					
		Crushing of crossing nose																					

Innotrack: SP1 - Summary of Results from National Infrastructure Managers' Workshops

Component	Problems	Suggested Causes	Extent of Problem								Countries Reporting Problem								Priority Rating				
			12%	25%	37%	50%	62%	75%	87%	100%	ADIF	RFF	BV	CD	DB	PR	OeBB	NR	1	2	3	4	5
Track	Bad track geometry	Frost heaving																					
		Soft sub-structure																					
		High vehicle forces																					
		Track not in designed position																					
		Sub-optimal maintenance																					
		Wrong/unknown stress-free temperature																					
		Bogie suspension bottoming out																					
		Inadequate management of wheel set defects																					
		Poor fault prediction																					
		Rail pad design and renewal																					
		Ballast does not meet design specification																					
		Inadequate design and maintenance of level crossings																					
	Reduced line speeds after maintenance work																						
	Limited access for inspection																						
	Noise																						
	Quality assurance																						

Innotrack: SP1 - Summary of Results from National Infrastructure Managers' Workshops

Component	Problems	Suggested Causes	Extent of Problem								Countries Reporting Problem								Priority Rating				
			12%	25%	37%	50%	62%	75%	87%	100%	ADIF	RFF	BV	CD	DB	PR	OeBB	NR	1	2	3	4	5
Joints	Electrical shorting in isolation joints	Metal flaws, plastic deformation	■	■	■						■		■					■			■		
	Stressing rails during welding		■															■				■	
	Weld quality		■	■							■							■			■		
	Fishplate failure on monoblock crossings	Insufficient support at joint	■								■											■	
Rail	Wear	Lack of lubrication	■	■									■					■					
		Wheel/rail profile not correct	■	■									■					■					
		Tight curves	■										■										
		Incorrect rail inclination	■								■											■	
	Corrugation	High unsprung wheel mass	■										■										
		Spinning wheel	■										■										
		Vehicle / track interaction	■								■									■			
		Wheel flats and/or oval wheels	■								■										■		
	Low friction/traction	Leaf fall into track	■	■									■					■					
	Cracks, Fatigue	High dynamic forces (eg wheel flats)	■	■									■					■					
		Low wear resulting in crack growth	■										■										
		Residual stresses after straightening	■													■							
		Bad wheel/rail interface	■	■	■	■					■		■			■		■	■				
		Inclusions in rail steel	■								■										■		
		Incorrect stress free temperature	■								■									■			
	Squats	Wheel slip	■	■							■					■					■		
	Residual stresses		■															■					
	Corrosion		■															■					

Innotrack: SP1 - Summary of Results from National Infrastructure Managers' Workshops

Component	Problems	Suggested Causes	Extent of Problem								Countries Reporting Problem								Priority Rating				
			12%	25%	37%	50%	62%	75%	87%	100%	ADIF	RFF	BV	CD	DB	PR	OeBB	NR	1	2	3	4	5
Sub-structure	Unstable	Soft sub-structure, wet bed	■	■	■	■					■		■				■	■			■		
Ballast	Stone spray	Ice clumps drops from vehicles	■										■										
	Ballast wear	Vehicle / track interaction	■	■							■						■					■	
Culvert/pipes	Collapsed	High axle load	■										■										
	Flooding	Culverts/pipes plugged with dirt	■	■							■		■								■		
Sleepers	Difficulties to decide when to replace	Rotten wood	■	■									■					■					
	Cracked concrete monoblock sleepers	Alkali-silica reaction	■								■											■	
		Manufacturing problems	■								■										■		
	Gauge spread with twin block concrete sleepers	Failure of steel tie between blocks	■								■										■		
Fasteners	Worn/missing pads	Dynamic forces from trains	■	■									■					■					
	Loose fasteners	Incorrect torque	■								■										■		
Structures (bridges and embankments)	Failures/Traffic disturbances/High costs	Maintence strategy poor/missing	■	■									■					■					
		Climate: snow, ice, rain, heat, sun-related failures	■	■									■					■					
Vehicles	Cargo dropped	Leaking/Open cars	■										■										
General	Cost of complying with TSIs		■															■					

Figure 10 -Results of ADIF IM Workshop Phase 2

7.12 Annex M: RFF IM Workshop – Phase 2 Results

Innotrack: SP1 - Summary of Results from National Infrastructure Managers' Workshops

Component	Problems	Suggested Causes	Extent of Problem								Countries Reporting Problem							
			12%	25%	37%	50%	62%	75%	87%	100%	ADIF	RFF	BV	CD	DB	PR	OeBB	NR
Track	Bad track geometry	Frost heaving										4	2					
		Soft sub-structure / drainage problems									2	2	2		1			
		High vehicle forces									3	2	2					
		Track not in designed position									2	4	2					
		Sub-optimal maintenance										3			1			
		Wrong/unknown stress-free temperature									2	4	2					
		Bogie suspension bottoming out										na	1					
		Inadequate management of wheel set defects										4						
		Poor fault prediction										3						
		Rail pad design and renewal										3						
		Ballast does not meet design specification										2						
		Inadequate design and maintenance of level crossings										3						
Switches and Crossings	Wear in switches	Bad track geometry in front of the switch										3	4					
		Wheel condition										3	4					
		Bogie design										4	4					
		Sub-optimal rail lubrication										4						
		Sub-structure										3	4					
		Tight radii (>500m)										4			2			
		RCF										2	2		1			
1 - Most important		2 - Important				3 - Of concern					4 - Least important							

Innotrack: SP1 - Summary of Results from National Infrastructure Managers' Workshops

Component	Problems	Suggested Causes	Extent of Problem								Countries Reporting Problem							
			12%	25%	37%	50%	62%	75%	87%	100%	ADIF	RFF	BV	CD	DB	PR	OeBB	NR
Rail	Cracks, Fatigue	High dynamic forces (eg wheel flats)										4	1					
		Low wear resulting in crack growth										2	1					
		Residual stresses after straightening										na						
		Bad wheel/rail interface									1	1	1		1			
		Inclusions in rail steel									1	3						
		Incorrect stress free temperature									1	4						
		Creep forces									1	2			1			
Sub-structure	Unstable	Soft sub-structure, wet bed									3	1	1		1			
Joints	Electrical shorting in isolation joints	Metal flaws, plastic deformation									3	1	1					
Rail	Wear	Lack of lubrication										1	2					
		Wheel/rail profile not correct										na	2					
		Tight curves										1	2					
		Incorrect rail inclination									4	4						
Rail	Corrugation	High unsprung wheel mass										4	1					
		Spinning wheel										4	1					
		Vehicle / track interaction									2	na						
		Wheel flats and/or oval wheels									3	na						
		No reason given										na			3			
Switches and Crossings	Point 'detection' problems	Blades blocked by snow/ice drops from vehicle										3	4					
		Detection is '100% / 0%'										na			2			
Switches and Crossings	Maintenance of geometry	We don't know the optimum maintenance requirement										3			1			
1 - Most important		2 - Important				3 - Of concern					4 - Least important							

Innotrack: SP1 - Summary of Results from National Infrastructure Managers' Workshops

Component	Problems	Suggested Causes	Extent of Problem								Countries Reporting Problem							
			12%	25%	37%	50%	62%	75%	87%	100%	ADIF	RFF	BV	CD	DB	PR	OeBB	NR
Switches and Crossings	Cracks in cast manganese crossings	High axle loads/high speeds/inadequate maintenance after installation										2	3					
		Weld quality / Management of heat affected zone										3			2			
Joints	Weld quality	None suggested									3	3						
Rail	Low friction/traction	Leaf fall into track										1	1					
Ballast	Ballast wear	Vehicle / track interaction									4	1						
Culverts/Pipes	Flooding	Culverts/pipes plugged with dirt									3	2	1					
Sleepers	Difficulties to decide when to replace	Rotten wood										3	1					
Fasteners	Worn/missing pads	Dynamic forces from trains										4	1					
Structures (bridges and embankments)	Failures/Traffic disturbances/High costs	Maintence strategy poor/missing										3	1					
		Climate: snow, ice, rain, heat, sun-related failures										3	1					
1 - Most important		2 - Important				3 - Of concern					4 - Least important							

Figure 11 - Results of RFF IM Workshop Phase 2

7.13 Annex N: BV IM Workshop – Phase 2 Results

Innotrack: SP1 - Summary of Results from National Infrastructure Managers' Workshops

Component	Problems	Suggested Causes	Extent of Problem								Countries Reporting Problem								Swedish Priority Rating (1=highest)				
			12%	25%	37%	50%	62%	75%	87%	100%	ADIF	RFF	BV	CD	DB	PR	OeBB	NR	1	2	3	4	5
Switches and Crossings	Switch blade not in position	Snow/ice drops from vehicle	■										■							■			
	Maintenance of geometry		■															■					
	Reliability of switch diamonds		■															■					
	Cracks in manganese crossing	High axle loads/high speeds/inadequate maintenance after installation	■										■								■		
	Wear in switches	Bad track geometry in front of the switch	■										■						■				
		Wheel condition	■										■						■				
		Bogie design	■										■							■			
		Sub-optimal rail lubrication	■															■					
		Sub-structure	■	■	■								■				■	■	■				
	RCF in switches		■	■									■			■						■	
	Failure of stock rail	Initial crack in fillet radius	■								■												
	Wear and failure of common crossings	High fatigue load due to loss of geometry	■								■												
	Reduction of gauge	Crushing of rail head	■								■												
		Crushing of crossing nose	■								■												

Innotrack: SP1 - Summary of Results from National Infrastructure Managers' Workshops

Component	Problems	Suggested Causes	Extent of Problem								Countries Reporting Problem								Swedish Priority Rating (1=highest)				
			12%	25%	37%	50%	62%	75%	87%	100%	ADIF	RFF	BV	CD	DB	PR	OeBB	NR	1	2	3	4	5
Track	Bad track geometry	Frost heaving	■										■									■	
		Soft sub-structure	■	■	■	■					■		■				■	■				■	
		High vehicle forces	■	■	■						■		■			■						■	
		Track not in designed position	■	■							■		■									■	
		Sub-optimal maintenance	■	■													■	■				■	
		Wrong/unknown stress-free temperature	■	■	■						■		■									■	
		Bogie suspension bottoming out	■										■										■
		Inadequate management of wheel set defects	■															■					
		Poor fault prediction	■															■					
		Rail pad design and renewal	■															■					
		Ballast does not meet design specification	■															■					
		Inadequate design and maintenance of level crossings	■															■					
	Reduced line speeds after maintenance work		■															■					
	Limited access for inspection		■															■					
	Noise		■													■							
	Quality assurance		■																				

Innotrack: SP1 - Summary of Results from National Infrastructure Managers' Workshops

Component	Problems	Suggested Causes	Extent of Problem								Countries Reporting Problem								Swedish Priority Rating (1=highest)				
			12%	25%	37%	50%	62%	75%	87%	100%	ADIF	RFF	BV	CD	DB	PR	OeBB	NR	1	2	3	4	5
Joints	Electrical shorting in isolation joints	Metal flaws, plastic deformation	■	■	■						■		■					■					■
	Stressing rails during welding		■															■					
	Weld quality		■	■							■							■					
	Fishplate failure on monoblock crossings	Insufficient support at joint	■								■												
Rail	Wear	Lack of lubrication	■	■									■					■		■			
		Wheel/rail profile not correct	■	■														■			■		
		Tight curves	■										■							■			
		Incorrect rail inclination	■								■												
	Corrugation	High unsprung wheel mass	■										■							■			
		Spinning wheel	■										■								■		
		Vehicle / track interaction	■								■												
		Wheel flats and/or oval wheels	■								■												
	Low friction/traction	Leaf fall into track	■	■									■					■			■		
	Cracks, Fatigue	High dynamic forces (eg wheel flats)	■	■									■					■		■			
		Low wear resulting in crack growth	■										■									■	
		Residual stresses after straightening	■													■							
		Bad wheel/rail interface	■	■	■	■					■		■			■		■		■			
		Inclusions in rail steel	■								■												
		Incorrect stress free temperature	■								■												
	Squats	Wheel slip	■	■							■					■							
	Residual stresses		■															■					
	Corrosion		■																				

Innotrack: SP1 - Summary of Results from National Infrastructure Managers' Workshops

Component	Problems	Suggested Causes	Extent of Problem								Countries Reporting Problem								Swedish Priority Rating (1=highest)				
			12%	25%	37%	50%	62%	75%	87%	100%	ADIF	RFF	BV	CD	DB	PR	OeBB	NR	1	2	3	4	5
Sub-structure	Unstable	Soft sub-structure, wet bed	■	■	■	■					■		■				■	■				■	
Ballast	Stone spray	Ice clumps drops from vehicles	■										■										■
	Ballast wear	Vehicle / track interaction	■	■							■						■						
Culvert/pipes	Collapsed	High axle load	■										■										■
	Flooding	Culverts/pipes plugged with dirt	■	■							■												■
Sleepers	Difficulties to decide when to replace	Rotten wood	■	■									■					■					■
	Cracked concrete monoblock sleepers	Alkali-silica reaction	■								■												
		Manufacturing problems	■								■												
	Gauge spread with twin block concrete sleepers	Failure of steel tie between blocks	■								■												
Fasteners	Worn/missing pads	Dynamic forces from trains	■	■									■					■					■
	Loose fasteners	Incorrect torque	■								■												
Structures (bridges and embankments)	Failures/Traffic disturbances/High costs	Maintence strategy poor/missing	■	■									■					■					■
		Climate: snow, ice, rain, heat, sun-related failures	■	■									■					■					■
Vehicles	Cargo dropped	Leaking/Open cars	■										■					■					■
General	Cost of complying with TSIs		■															■					

Figure 12 - Results of BV IM Workshop Phase 2

7.14 Annex P: ÖBB IM Workshop – Phase 2 Results

Innotrack: SP1 - Summary of Results from National Infrastructure Managers' Workshops

Component	Problems	Suggested Causes	Extent of Problem								Countries Reporting Problem								Priority Rating				
			12%	25%	37%	50%	62%	75%	87%	100%	ADIF	RFF	BV	CD	DB	PR	ÖeBB	IIR	1	2	3	4	5
Switches and Crossings	Tongue/blade not in position	Snow/ice drops from vehicle	■										■										■
	Maintenance of geometry		■															■			■		
	Reliability of switch diamonds		■															■					■
	Cracks in manganese crossing	High axle loads/high speeds/inadequate maintenance after installation	■										■									■	
	Wear in switches	Bad track geometry in front of the switch	■										■									■	
		Wheel condition	■										■									■	
		Bogie design	■										■									■	
		Sub-optimal rail lubrication	■															■					■
		Sub-structure	■	■	■								■					■					■
	RCF in switches		■	■									■			■					■		
	Failure of stock rail	Initial crack in fillet radius	■								■												■
	Wear and failure of common crossings	High fatigue load due to loss of geometry	■								■										■		
	Reduction of gauge	Crushing of rail head	■								■											■	
		Crushing of crossing nose	■								■												■

Innotrack: SP1 - Summary of Results from National Infrastructure Managers' Workshops

Component	Problems	Suggested Causes	Extent of Problem								Countries Reporting Problem								Priority Rating				
			12%	25%	37%	50%	62%	75%	87%	100%	ADIF	RFF	BV	CD	DB	PR	ÖeBB	IIR	1	2	3	4	5
Track	Bad track geometry	Frost heaving	■										■									■	
		Soft sub-structure	■	■	■	■					■		■				■	■	■				
		High vehicle forces	■	■	■						■		■			■					■		
		Track not in designed position	■	■							■		■										■
		Sub-optimal maintenance	■	■														■				■	
		Wrong/unknown stress-free temperature	■	■	■						■		■					■					■
		Bogie suspension bottoming out	■										■									■	
		Inadequate management of wheel set defects	■															■				■	
		Poor fault prediction	■														?	■					
		Rail pad design and renewal	■															■				■	
		Ballast does not meet design specification	■															■					■
		Inadequate design and maintenance of level crossings	■															■			■		
	Reduced line speeds after maintenance work		■															■					
	Limited access for inspection		■															■					■
	Noise		■													■						■	
	Quality assurance		■													■						■	

Figure 13 - Results of ÖBB IM Workshop Phase 2

7.15 Annex R: NR IM Workshop – Phase 2 Results

Innotrack: SP1 - Summary of Results from National Infrastructure Managers' Workshops

Component	Problems	Suggested Causes	Extent of Problem								Countries Reporting Problem								Track	Maintenance
			12%	25%	37%	50%	62%	75%	87%	100%	E	F	S	CZ	D	NL	A	UK		
Track	Bad track geometry	Frost heaving											4							
		Soft sub-structure / drainage problems									2		4		1		1	1	2	1
		High vehicle forces									3		4							
		Track not in designed position									2		4							
		Sub-optimal maintenance													1		4	2	3	2
		Wrong/unknown stress-free temperature									2		4					1	1	3
		Bogie suspension bottoming out											4							
		Inadequate management of wheel set defects																2	2	
		Poor fault prediction																2	4	2
		Rail pad design and renewal																3	3	
		Ballast does not meet design specification																3	3	
		Inadequate design and maintenance of level crossings																2	2	
Switches and Crossings	Wear in switches	Bad track geometry in front of the switch											1							
		Wheel condition											1							
		Bogie design											2							
		Sub-optimal rail lubrication																3	4	3
		Sub-structure											1				4	1	3	1
		Tight radii (>500m)													2					
		RCF											4		1			2		2
1 - Most important		2 - Important									3 - Of concern							4 - Least important		

Innotrack: SP1 - Summary of Results from National Infrastructure Managers' Workshops

Component	Problems	Suggested Causes	Extent of Problem								Countries Reporting Problem								Track	Maintenance
			12%	25%	37%	50%	62%	75%	87%	100%	E	F	S	CZ	D	NL	A	UK		
Rail	Cracks, Fatigue	High dynamic forces (eg wheel flats)											4					1	1	1
		Low wear resulting in crack growth											4							
		Residual stresses after straightening																		
		Bad wheel/rail interface									1		4		1			1	2	1
		Inclusions in rail steel									1									
		Incorrect stress free temperature									1									
		Creep forces									1				1					
Sub-structure	Unstable	Soft sub-structure, wet bed									3		4		1		2	1	1	1
Joints	Electrical shorting in isolation joints	Metal flaws, plastic deformation									3		4					2	2	
Rail	Wear	Lack of lubrication											4					2	4	2
		Wheel/rail profile not correct											4					2	2	2
		Tight curves											4				1			
		Incorrect rail inclination									4									
Rail	Corrugation	High unsprung wheel mass											4							
		Spinning wheel											4							
		Vehicle / track interaction									2						1			
		Wheel flats and/or oval wheels									3									
		No reason given													3					
Switches and Crossings	Point 'detection' problems	Blades blocked by snow/ice drops from vehicle											2							
		Detection is '100% / 0%'													2					
Switches and Crossings	Maintenance of geometry	We don't know the optimum maintenance requirement													1			3	3	
1 - Most important		2 - Important									3 - Of concern							4 - Least important		

Innotrack: SP1 - Summary of Results from National Infrastructure Managers' Workshops

Component	Problems	Suggested Causes	Extent of Problem								Countries Reporting Problem								Track	Maintenance
			12%	25%	37%	50%	62%	75%	87%	100%	E	F	S	CZ	D	NL	A	UK		
Switches and Crossings	Cracks in cast manganese crossings	High axle loads/high speeds/inadequate maintenance after installation											3					3		3
		Weld quality / Management of heat affected zone													2					
Joints	Weld quality	None suggested									3							2	2	3
Rail	Low friction/traction	Leaf fall into track											4					3	4	3
Ballast	Ballast wear	Vehicle / track interaction									4						4			
Culverts/Pipes	Flooding	Culverts/pipes plugged with dirt									3		4					2		2
Sleepers	Difficulties to decide when to replace	Rotten wood											4					3	3	
Fasteners	Worn/missing pads	Dynamic forces from trains											4				2	2	2	
Structures (bridges and embankments)	Failures/Traffic disturbances/High costs	Maintence strategy poor/missing											4					3	3	
		Climate: snow, ice, rain, heat, sun-related failures											4					3	3	
1 - Most important		2 - Important									3 - Of concern							4 - Least important		

Figure 14 - Results of NR IM Workshop Phase 2

7.16 Annex S: Consolidated Results of IM Workshops Phase 2

Innotrack: SP1 - Summary of Results from National Infrastructure Managers' Workshops

Component	Problems	Suggested Causes	Extent of Problem								Countries Reporting Problem							
			12%	25%	37%	50%	62%	75%	87%	100%	ADIF	RFF	BV	CD	DB	PR	OeBB	NR
Track	Bad track geometry	Frost heaving											4					
		Soft sub-structure / drainage problems									2		4		1		1	1
		High vehicle forces									3		4					
		Track not in designed position									2		4					
		Sub-optimal maintenance													1		4	2
		Wrong/unknown stress-free temperature									2		4					1
		Bogie suspension bottoming out											4					
		Inadequate management of wheel set defects																2
		Poor fault prediction																2
		Rail pad design and renewal																3
		Ballast does not meet design specification																3
		Inadequate design and maintenance of level crossings																2
Switches and Crossings	Wear in switches	Bad track geometry in front of the switch											1					
		Wheel condition											1					
		Bogie design											2					
		Sub-optimal rail lubrication																3
		Sub-structure											1				4	1
		Tight radii (>500m)													2			
		RCF											4		1			2
		Failure of common crossings									4							

1 - Most important | 2 - Important | 3 - Of concern | 4 - Least important

Innotrack: SP1 - Summary of Results from National Infrastructure Managers' Workshops

Component	Problems	Suggested Causes	Extent of Problem								Countries Reporting Problem							
			12%	25%	37%	50%	62%	75%	87%	100%	ADIF	RFF	BV	CD	DB	PR	OeBB	NR
Rail	Cracks, Fatigue	High dynamic forces (eg wheel flats)											4					1
		Low wear resulting in crack growth											4					
		Residual stresses after straightening																
		Bad wheel/rail interface									1		4		1			1
		Inclusions in rail steel									1							
		Incorrect stress free temperature									1							
		Creep forces									1				1			
Sub-structure	Unstable	Soft sub-structure, wet bed									3		4		1		2	1
Joints	Electrical shorting in isolation joints	Metal flaws, plastic deformation									3		4					2
Rail	Wear	Lack of lubrication											4					2
		Wheel/rail profile not correct											4					2
		Tight curves											4					
		Incorrect rail inclination									4							
Rail	Corrugation	High unsprung wheel mass											4					
		Spinning wheel											4					
		Vehicle / track interaction									2							
		Wheel flats and/or oval wheels									3							
		No reason given													3			
Switches and Crossings	Point 'detection' problems	Blades blocked by snow/ice drops from vehicle											2					
		Detection is '100% / 0%'													2			
Switches and Crossings	Maintenance of geometry	We don't know the optimum maintenance requirement													1			3

1 - Most important | 2 - Important | 3 - Of concern | 4 - Least important

Innotrack: SP1 - Summary of Results from National Infrastructure Managers' Workshops

Component	Problems	Suggested Causes	Extent of Problem								Countries Reporting Problem							
			12%	25%	37%	50%	62%	75%	87%	100%	ADIF	RFF	BV	CD	DB	PR	OeBB	NR
Switches and Crossings	Cracks in cast manganese crossings	High axle loads/high speeds/inadequate maintenance after installation											3					
		Weld quality / Management of heat affected zone													2			
Joints	Weld quality	None suggested									3							2
Rail	Low friction/traction	Leaf fall into track											4					3
Ballast	Ballast wear	Vehicle / track interaction									4						4	
	Stone spray																	
Culverts/Pipes	Flooding	Culverts/pipes plugged with dirt									3		4					
Sleepers	Difficulties to decide when to replace	Rotten wood											4					3
	Cracked monoblock	Alkali silica reaction									4							
Fasteners	Worn/missing pads	Dynamic forces from trains											4					2
Structures (bridges and embankments)	Failures/Traffic disturbances/High costs	Maintence strategy poor/missing											4					3
		Climate: snow, ice, rain, heat, sun-related failures											4					3
1 - Most important		2 - Important				3 - Of concern					4 - Least important							

Figure 15 - Consolidated Results of IM Workshops Phase 2, Showing Component Problems in Descending Order of Importance

7.17 Annex T: Schedule of Track Maintenance Problems and Underlying Causes in Descending Order of Importance

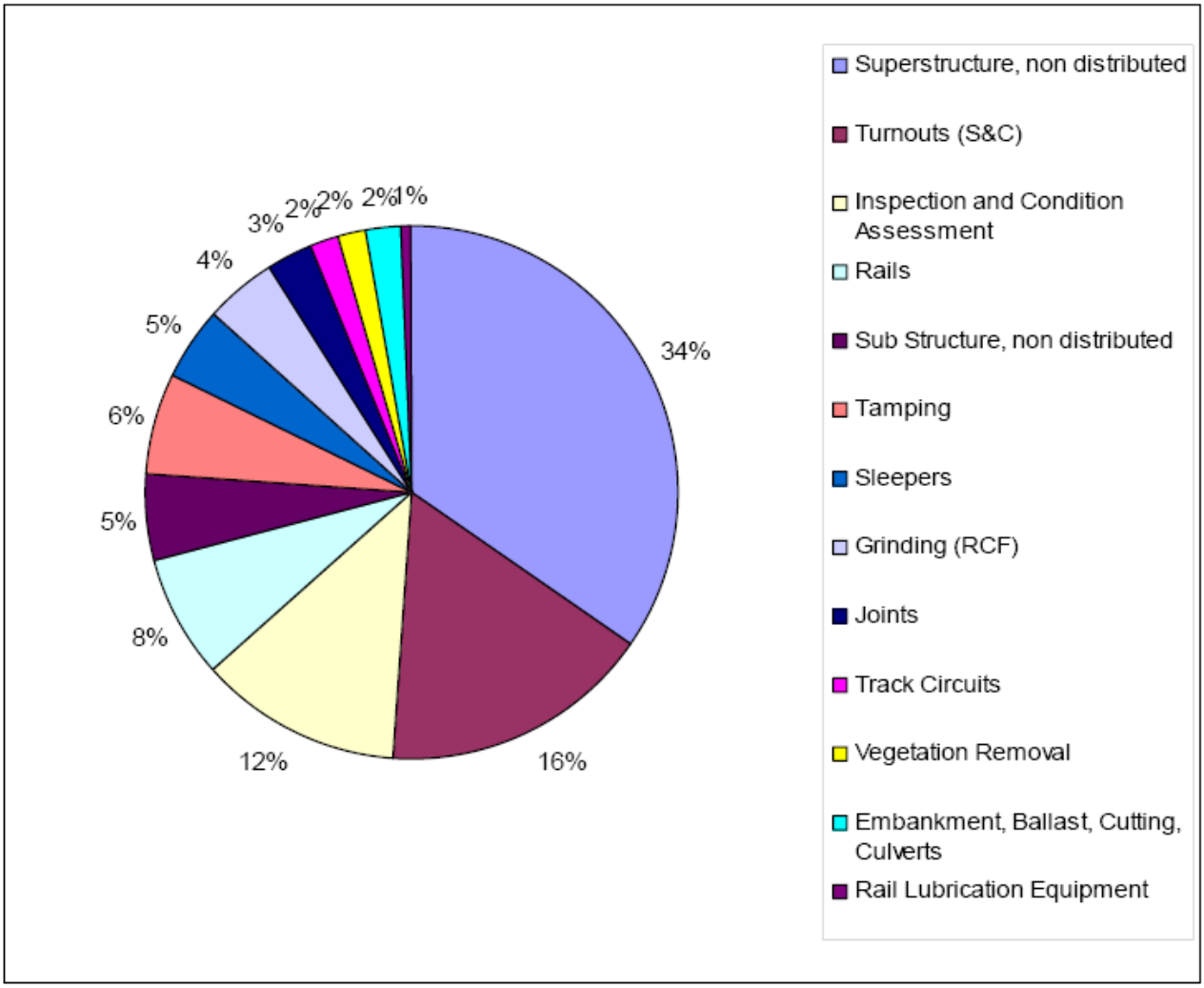
Innotrack: SP1 - Summary of Results from National Infrastructure Managers' Workshops

Component	Problems	Suggested Causes	Extent of Problem								Countries Reporting Problem							
			12%	25%	37%	50%	62%	75%	87%	100%	ADIF	RFF	BV	CD	DB	PR	OeBB	NR
Rail	Cracks, Fatigue	Creep forces									1				1			
Rail	Cracks, Fatigue	Bad wheel/rail interface									1		4		1			1
Track	Bad track geometry	Soft sub-structure / drainage problems									2		4		1		1	1
Switches and Crossings	Wear in switches	Sub-structure											1				4	1
Rail	Corrugation	Vehicle / track interaction									2							
Switches and Crossings	Cracked manganese	Weld quality													2			
Switches and Crossings	Maintenance of geometry	We don't know the optimum maintenance requirement													1			3
Sub-structure	Unstable	Soft sub-structure, wet bed									3		4		1		2	1
Track	Bad track geometry	Sub-optimal maintenance													1		4	2
Track	Bad track geometry	Wrong/unknown stress-free temperature									2		4					1
Switches and Crossings	Wear in switches	RCF											4		1			2
Rail	Cracks, Fatigue	High dynamic forces (eg wheel flats)											4					1
Joints	Weld quality	None suggested									3							2
Fasteners	Worn/missing pads	Dynamic forces from trains											4					2
Track	Bad track geometry	Track not in designed position									2		4					
Joints	Electrical shorting in isolation joints	Metal flaws, plastic deformation									3		4					2
Rail	Wear	Lack of lubrication											4					2
Rail	Wear	Wheel/rail profile not correct											4					2
Switches and Crossings	Cracks in cast manganese crossings	High axle loads/high speeds/inadequate maintenance after installation											3					
Culverts/Pipes	Flooding	Culverts/pipes plugged with dirt									3		4					
Track	Bad track geometry	High vehicle forces									3		4					
Rail	Low friction/traction	Leaf fall into track											4					3
Sleepers	Difficulties to decide when to replace	Rotten wood											4					3
Structures (bridges and embankments)	Failures/Traffic disturbances/High costs	Maintence strategy poor/missing											4					3
Structures (bridges and embankments)	Failures/Traffic disturbances/High costs	Climate: snow, ice, rain, heat, sun-related failures											4					3
Ballast	Ballast wear	Vehicle / track interaction									4						4	
Rail	Wear	Tight curves											4					
Sleepers	Cracked monoblock	Alkali silica reaction									4							
Ballast	Stone spray												4					
1 - Most important		2 - Important				3 - Of concern					4 - Least important							

Figure 16 - Schedule of Track Maintenance Problems and Underlying Causes in Descending Order of Importance

7.18 Annex U: IM Cost Category and Maintenance Spend Data

Cost drivers, based on maintenance cost 2006 (Reinvestment and snow removal excluded).



Comment:
A: The chart has a large part consisting of non-distributed superstructure costs. These are mainly costs related to outsourced maintenance performance contracts. Therefore it includes a lot of both rail and S & C maintenance costs.
B: The chart does not include reinvestment costs
C: Costs related to Culverts are strongly increased on lines with axle load exceeding 25 tonnes. The chart shows mean values for the entire railway net in Sweden.

Figure 17 - Cost Categories and Maintenance Spend for Banverket

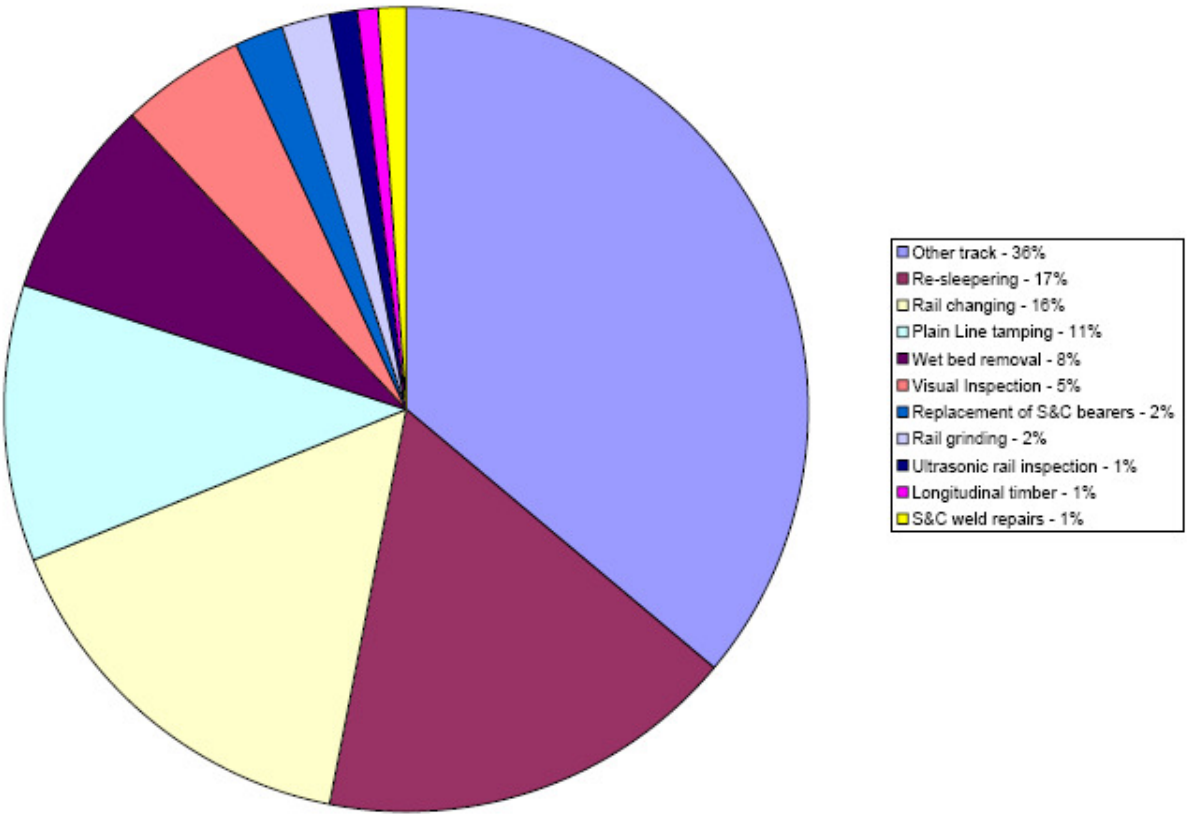


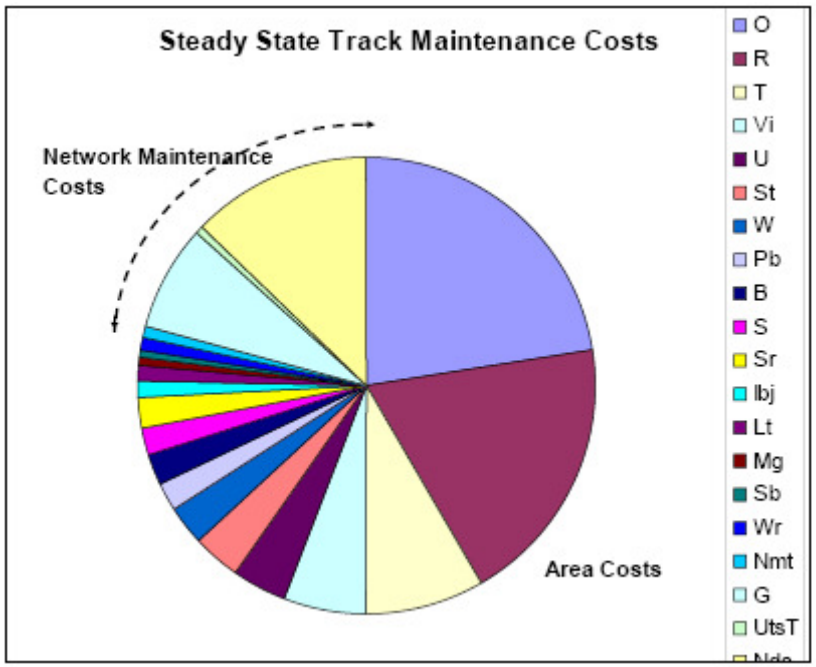
Figure 18 - Cost Categories and Maintenance Spend for ADIF

Cost Category	Percentage of Maintenance Budget (Normalised to exclude structures work)
Rail changing	5%
Track line and levelling	4%
Supervision	11%
S+C line and levelling	1%
Plain line ballast cleaning	8%
S+C ballast cleaning	3%
Re-sleepering	8%
CWR S+C	1%
CWR plain line	4%
Track recording car	4%
Grinding	2%
Other	49%

Figure 19 - Cost Categories and Maintenance Spend Data for CD

corrective maintainance (cm)	cm: track	2.2 %
	cm: switches + crossings	1.2 %
	cm: others	0.1 %
corrective repair sum		
inspection	Inspection of track	9.7 %
	inspection of switches + crossings (s&c)	4.1 %
Service	service: infrastructure gauge clearing	6.7 %
	service: switches and crosses greasing	1.3 %
	winterservice (snow clearing)	17.6 %
Inspection and Service sum		
preventive maintainance (pm)	pm: single sleeper replacement	1.8 %
	pm: rail alignment	2.9 %
	pm: systematic track work over	2.9 %
	pm: combination of tamping and grinding	0.7 %
	pm: tamping	8.2 %
	pm: rail grinding	1.8 %
	pm: rail replacement	7.4 %
	pm: general sleeper replacement	2.7 %
	pm: rail pads replacement	1.7 %
	pm: S&C build up welding	1.6 %
	pm: S&C tamping	5.5 %
	pm: S&C sleeper replacement	1.3 %
	pm: S&C grinding	0.7 %
	pm: S&C parts replacement	6.0 %
	pm: other track maintenance	11.9 %
track preventive maintainance sum		
Sum		100.0 %

Figure 20 - Cost Categories and Maintenance Spend for ÖBB



- Other track O
- Rail changing R
- Plain line tamping T
- Visual Inspection Vi
- Ultrasonic rail inspection U
- S&C tamping St
- Wet bed removal W
- Reprofiling of Ballast Pb
- Stone blowing B
- Re-sleepering S
- S&C unit renewal Sr
- Insulated joint renewal Ibj
- Longitudinal timber Lt
- Manual geometry correction Mg
- Replacement of S&C bearers Sb
- S&C weld repairs Sw
- Weld repair of defective rails Rw
- New Measurement Train Nmt
- Rail grinding G
- Ultrasonic test trains Utst
- Other NDS Costs Nds

Figure 21 - Cost Categories and Maintenance Spend for Network Rail

Track Maintenance Cost Percentages in Descending Order of Size

ADIF		Network Rail		CD		Banverket		OeBB		Overall Summary	
Maintenance Item	Percentage of Overall Track Maintenance Cost	Maintenance Item	Percentage of Overall Track Maintenance Cost	Maintenance Item	Percentage of Overall Track Maintenance Cost	Maintenance Item	Percentage of Overall Track Maintenance Cost	Maintenance Item	Percentage of Overall Track Maintenance Cost	Average Percentage Cost in Descending Order of Importance	
Re-sleepering	28	Plain line tamping	24	Inspection	22	S+C	27	S+C	28	S+C	18.4
Rail changing	25	Inspection	19	Ballast cleaning	20	Inspection	21	Inspection	19	Inspection	18.2
Plain line tamping	17	Rail changing	18	S+C	18	Rails	14	Rail Alignment (tamp)	16	Rail changing	16.8
Wet bed removal	13	S+C	15	Rail change	16	Tamping	11	Rail replacement	11	Tamping	15.2
Inspection	10	Ballast re-profiling	8	Re-sleepering	14	Sleepers	9	Gauge clearance	10	Re-sleeper	12.8
S+C	4	Re-sleepering	5	Tamping	8	Grinding	7	Re-sleepering	8	Grinding	4.3
Grinding	3	Weld repairs	5	Grinding	2	Joints	5	Grinding	5	Wet beds	2
		Wet bed removal	3			Vegetation	4	Rail pad replacement	3		
		Fish plate oiling	2			Lubrication	2				
		Insulated joint renewal	1								
	100		100		100		100		100		

Figure 22 - Summary of Cost Categories and Maintenance Spend for the five IMs

(See right hand column for key to colour coding. Spend labelled as 'Other' and 'Winter Service' removed from table and remaining percentages normalised)

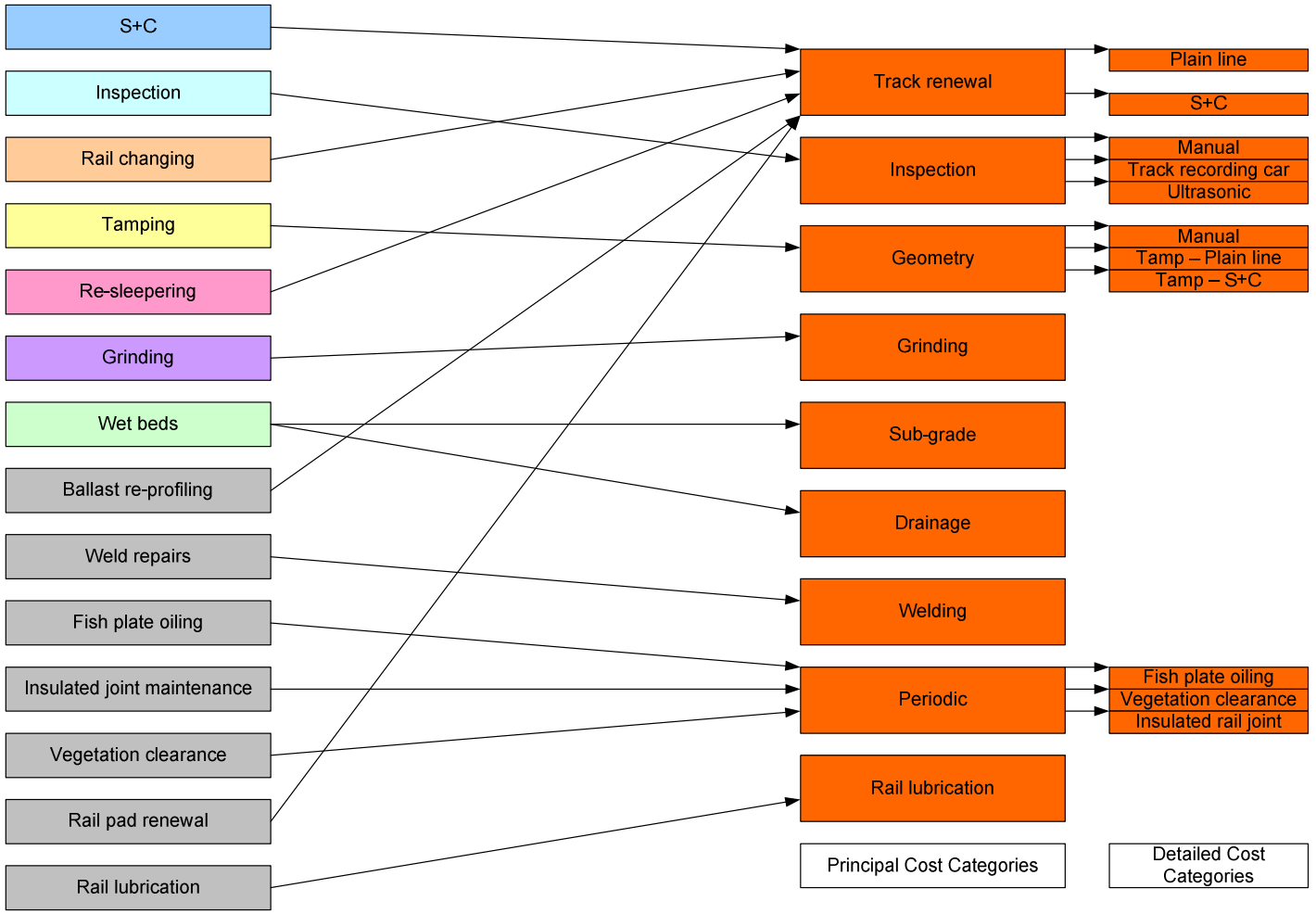


Figure 23 - Mapping of IM cost categories to suggested general set of European principal cost categories

7.19 Annex V: Relationships between principal faults and cost categories

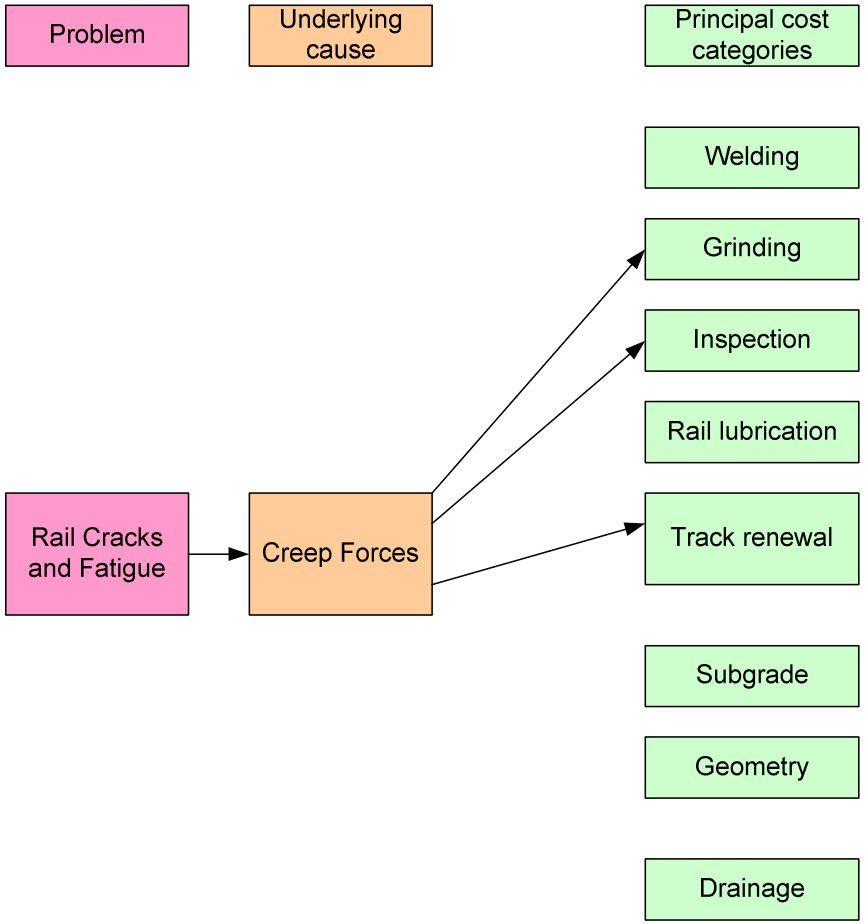


Figure 24 – Diagram linking rail cracks and fatigue caused by creep forces to maintenance cost categories

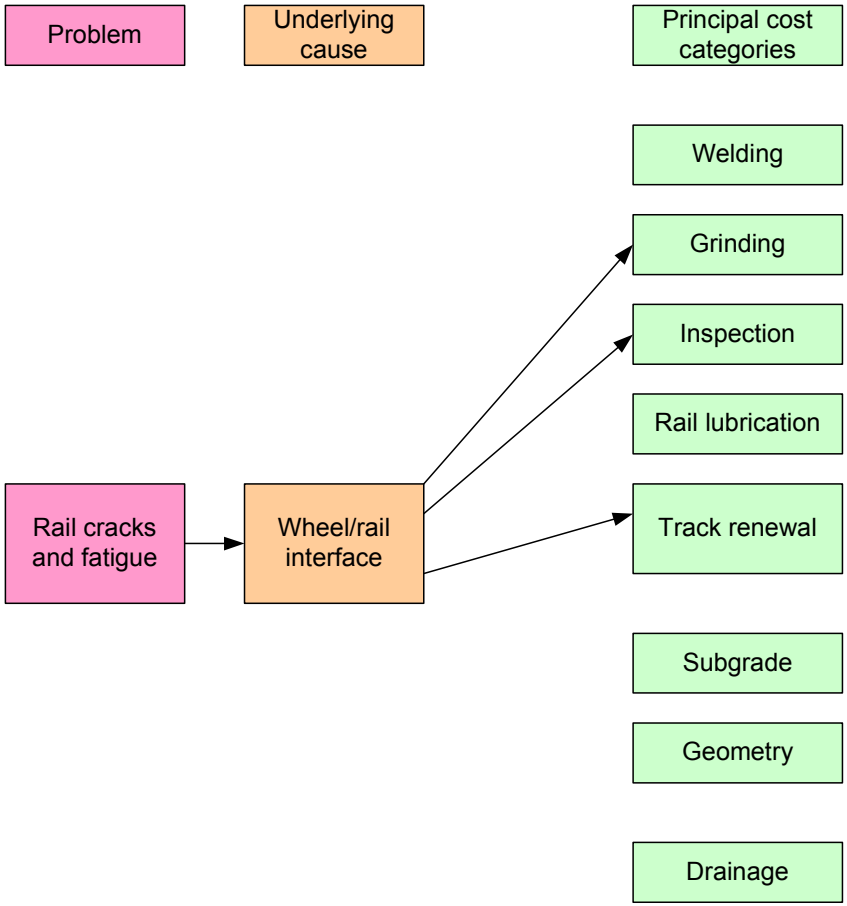


Figure 25 – Diagram linking rail cracks and fatigue caused by wheel-rail interface to maintenance cost categories

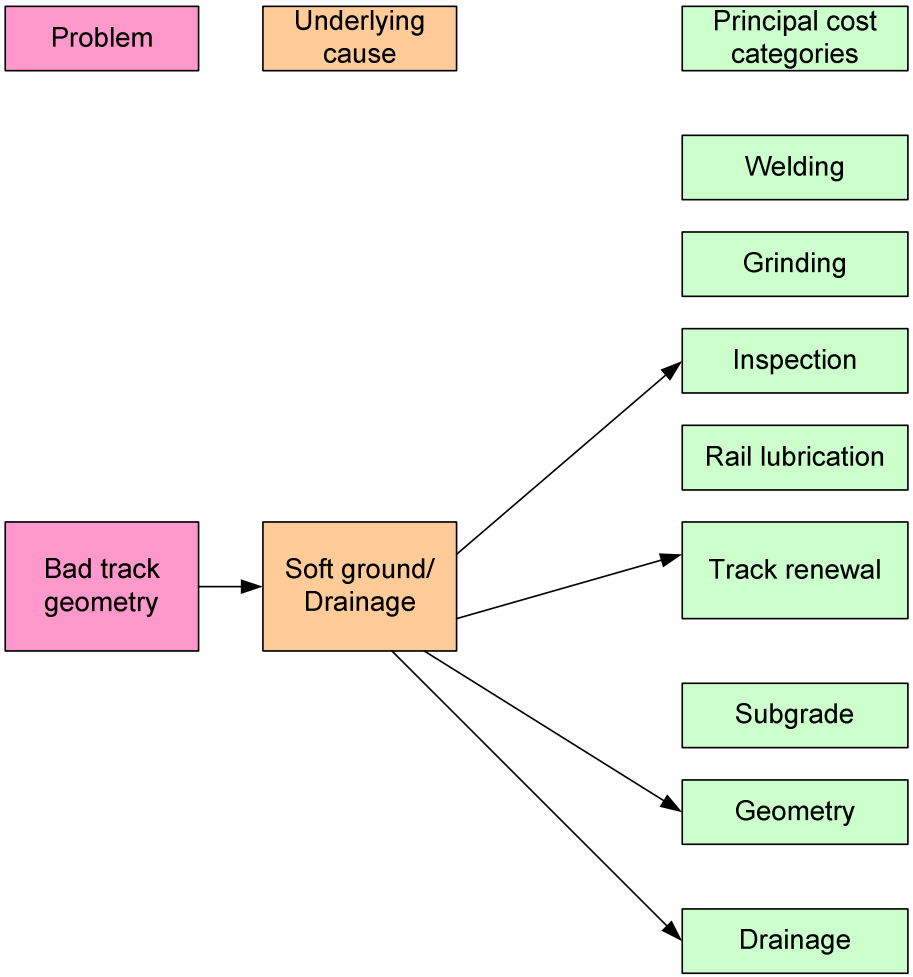


Figure 26 – Diagram linking bad track geometry caused by soft ground/drainage to maintenance cost categories

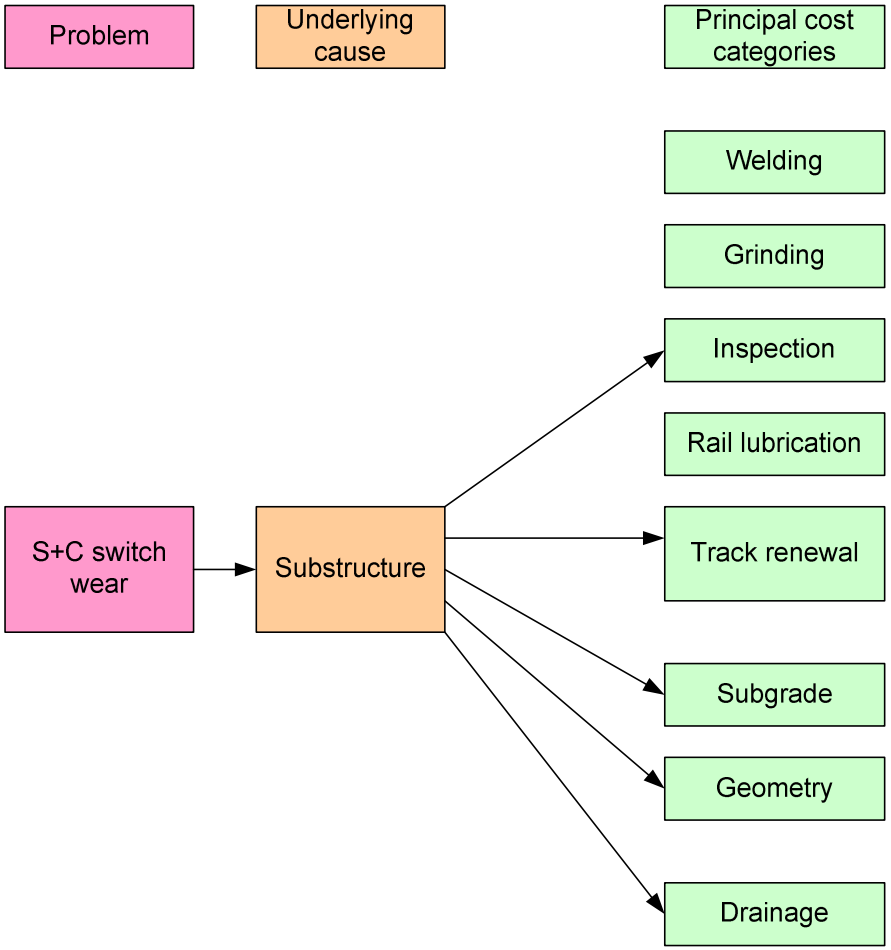


Figure 27 – Diagram linking bad track geometry caused by soft ground to maintenance cost categories

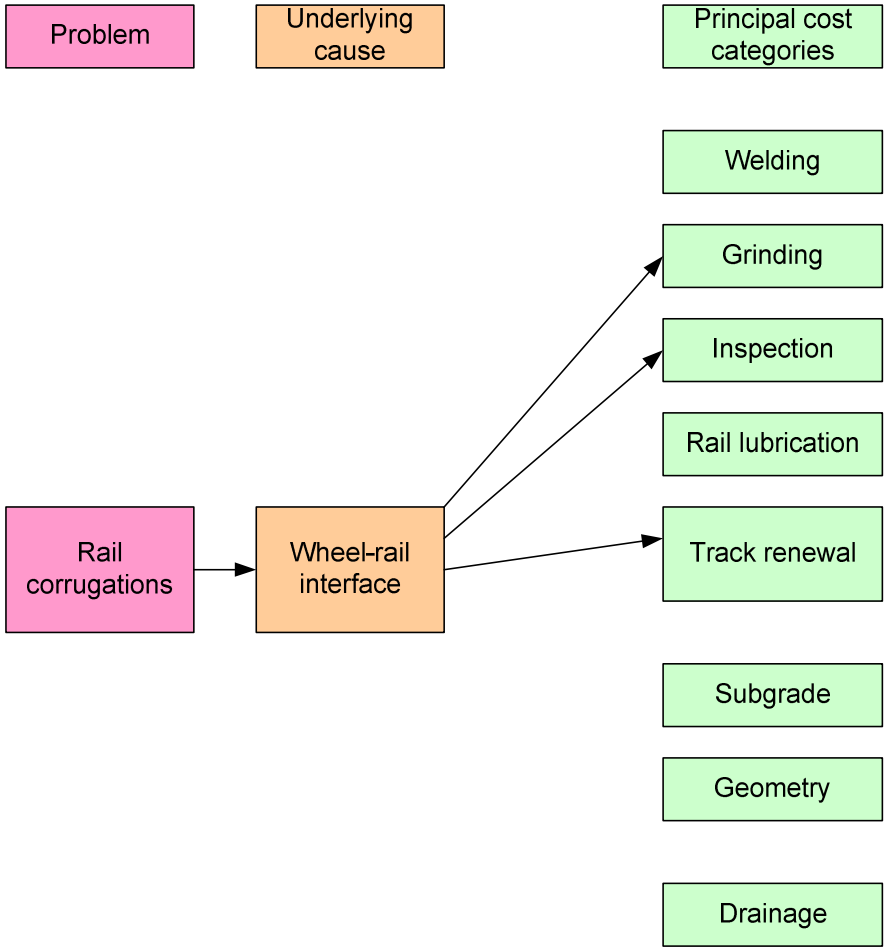


Figure 28 – Diagram linking rail corrugations caused by wheel-rail interface to maintenance cost categories

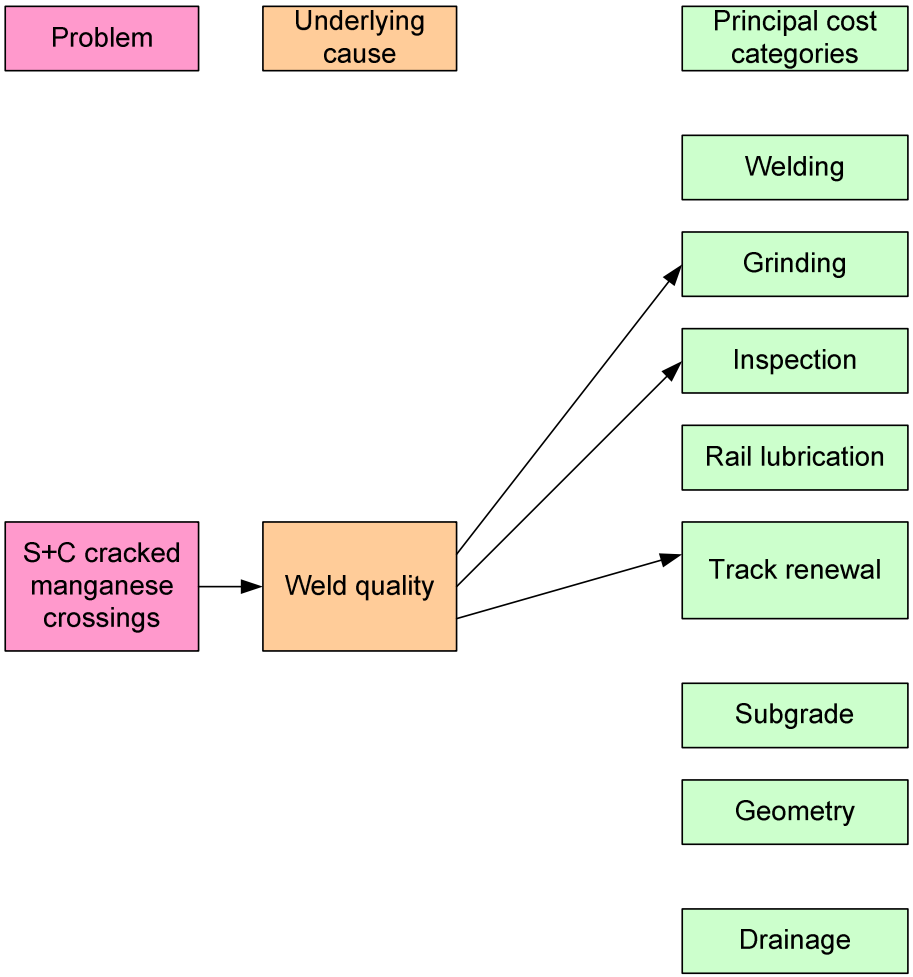


Figure 29 – Diagram linking S+C cracked manganese crossings caused by weld quality to maintenance cost categories

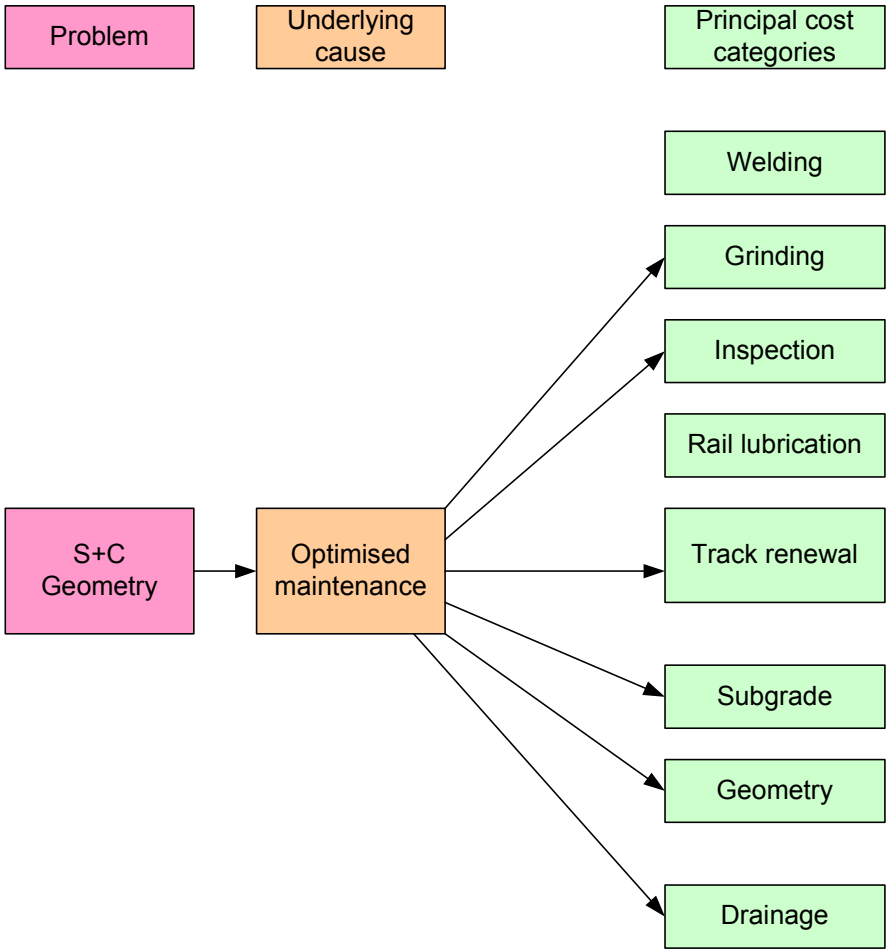


Figure 30 – Diagram linking S+C geometry optimisation to maintenance cost categories

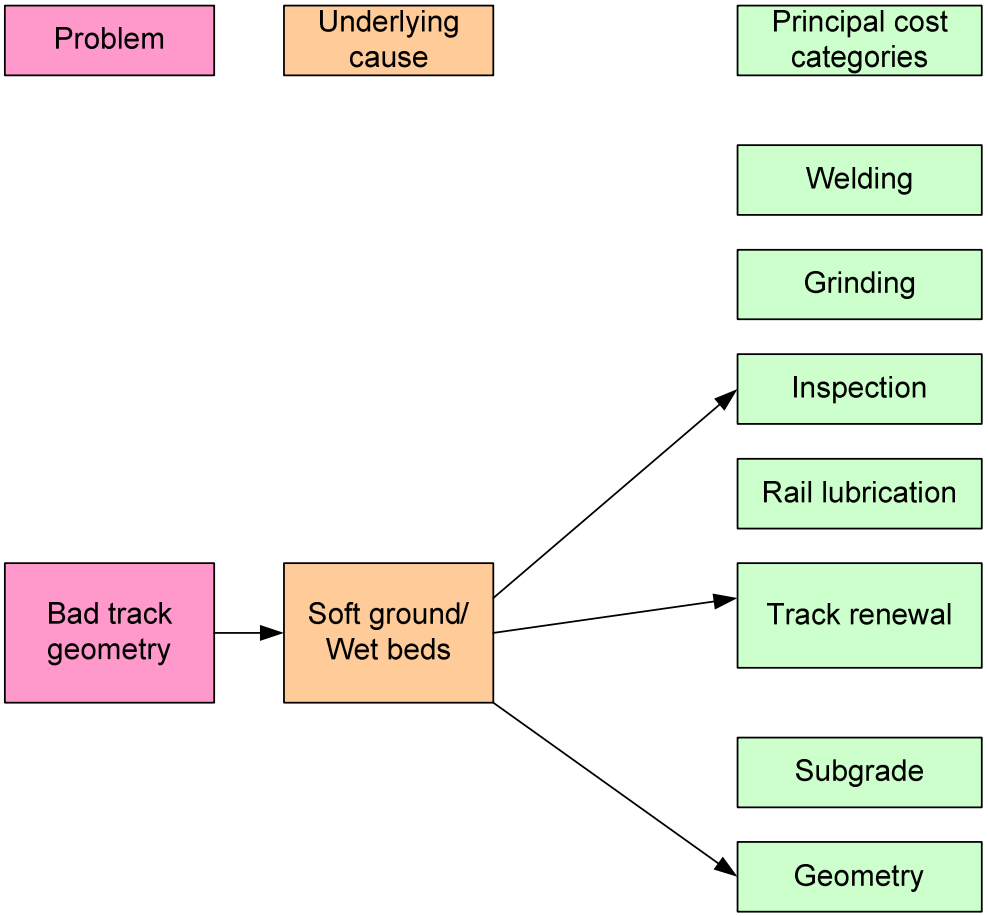


Figure 31 – Diagram linking bad track geometry caused by soft ground/wet beds to maintenance cost categories

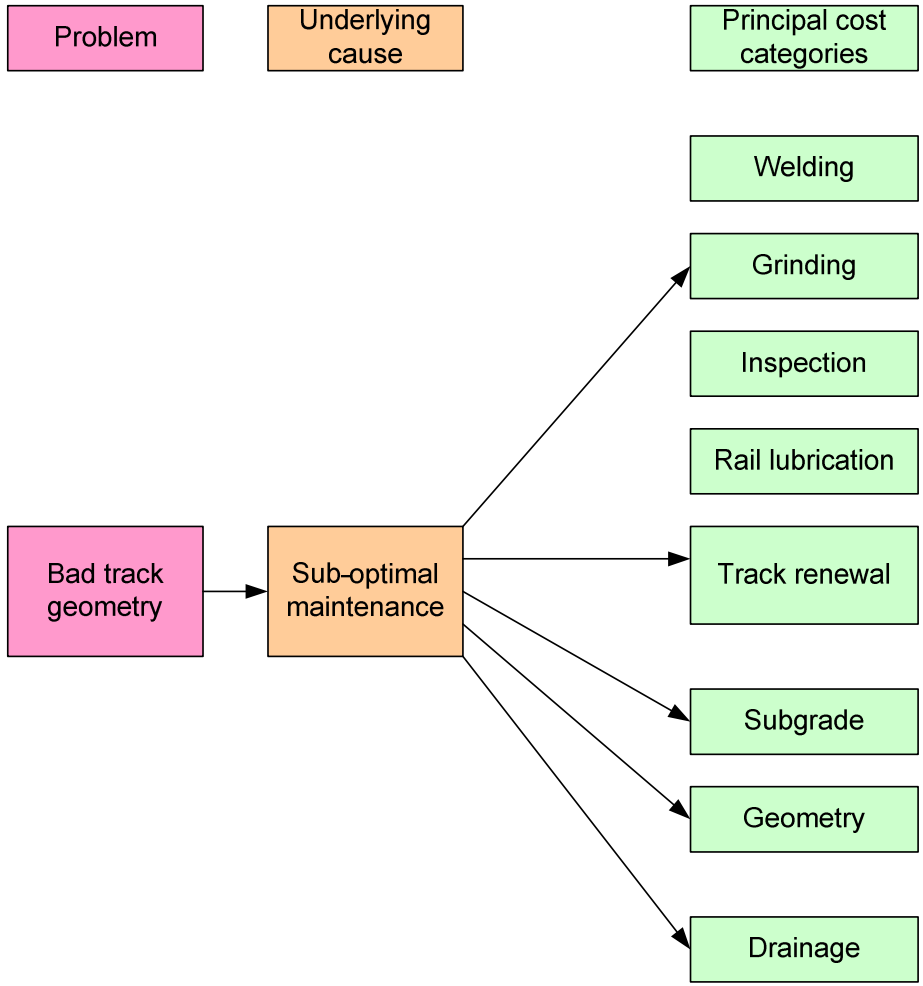


Figure 32 – Diagram linking bad track geometry caused by sub-optimal maintenance to maintenance cost categories

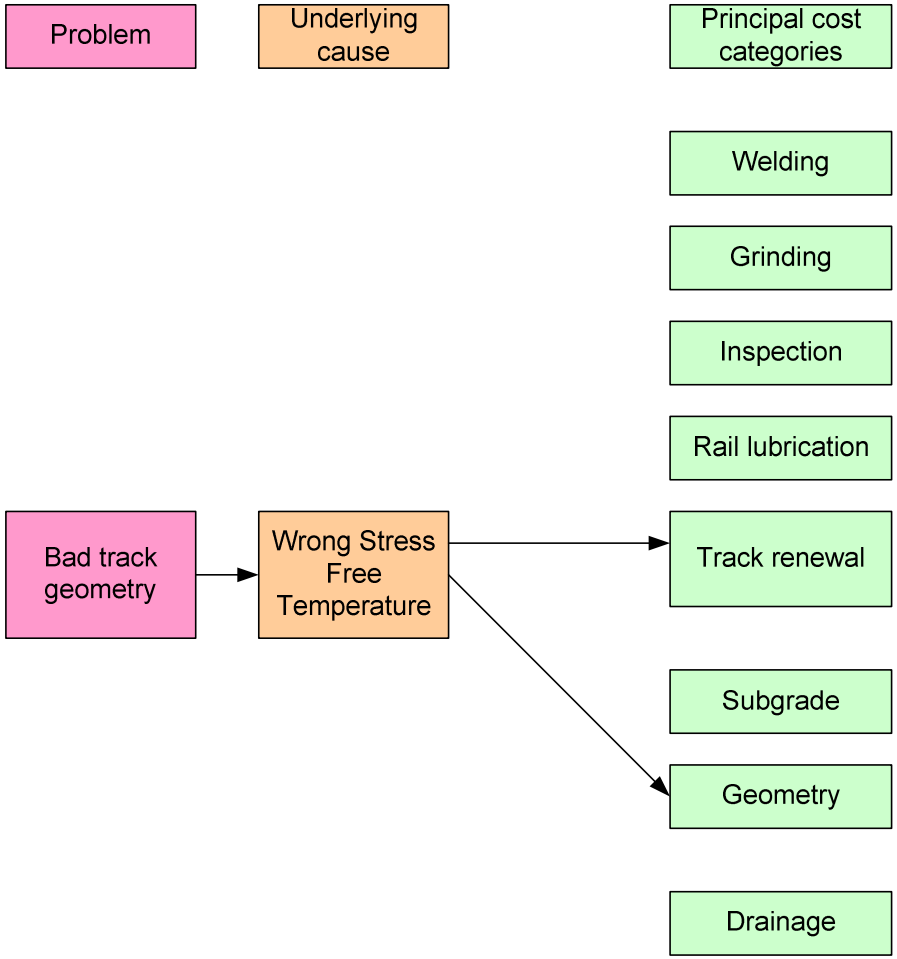


Figure 33 – Diagram linking bad track geometry caused by incorrect stress free temperature to maintenance cost categories