Det Norske Veritas

# Assessment of freight train derailment risk reduction measures:

## B3 – Top ten ranking of safety measures

Report for European Railway Agency
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MANAGING RISK DNV

Assessment of derailment risk reduction measures:
B3 –Top ten ranking of Safety Measures Rev 3
for

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Summary: This document presents a list of the top ten safety most efficient safety measures against freight train derailment

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# 0.0 Executive Summary

## 0.1 Introduction

In 2009 the European Railway Agency (the Agency) issued a recommendation (ERA/REC/01-2009/SAF) on a specific proposal, made by the RID Committee of Experts, for a new harmonised rule aimed at reducing the consequences of freight train derailments, potentially involving dangerous goods (DGs). The recommendation concerned the potential use of a Derailment Detection Devices (DDD[1]). This device automatically applies the brakes on a freight train when a derailment of a wagon equipped with that device is suspected.

Although the Agency's recommendation was that the DDD should not be adopted in the RID it was agreed that alternative prevention based measures should be further explored before deciding on imposing, by law, measures based on derailment detection.

Therefore recognising that freight train derailments remain a safety and operational concern, and following a request made by the European Commission, the Agency has commissioned further work with the objective of which is to carry out an exhaustive analysis of all prevention and mitigation measures which could reduce the risks related to freight train derailments.

Det Norske Veritas (DNV) was selected by the Agency to contribute to this work, the results of which are presented in this and related documents.

## 0.2 Project Scope and Objectives

The study is divided into two distinct research stages: Parts A and B.

Part A has the objective of identifying all prevention and mitigation measures that exist today or could be implemented within the short term (before 1st of January 2013) or medium term (ready to be voluntarily applied or to be introduced in EU regulation within 5 to 10 years).

Part B has the objective of analysing the measures identified in Part A with a view to identifying those that are the most efficient. Part B is scoped to include all prevention measures but is limited to mitigation measures based on derailment detection.

The geographical scope for this work is the EU-27 countries plus the 3 candidate countries (Turkey, Macedonia and Croatia), Norway and Switzerland (hereafter called the target countries). In addition, the USA and Japan are considered in the scope of safety measure identification, but limited to the most commonly used safety measures and to the foreseeable innovations at medium term.

## 0.3 Methodology

### 0.3.1 Part A: Measure Identification

Part A work sought to identify the existing use of freight train derailment risk reduction measures (technical, procedural or organisational) through a range of activities. These included:

- Direct consultation with a large number of Infrastructure Managers, Railway Undertakings, Wagon Owners, supplier organisations, industry bodies and other actors.
- In-house knowledge, literature and internet research.

[1] DDD is an acronym used to refer to a type of detector which automatically activates train brakes when a derailment is detected based on detection of wagon acceleration. Device type EDT-101 is an example of such a device.

Activity in this work package also included the identification of the existing application scope of identified measures, and also the collection of market and performance data for these measures.

### 0.3.2 Part B: Measures Assessment

Part B considered the problem of freight train derailment and its causes, and then how the measures identified in Part A could be used to improve the situation. This room for potential improvement can be achieved either through the wider use of existing measures, or the application of new measures.

These objectives were achieved through a series of tasks that included the following:

- Comprehensive review of freight train derailment accidents to establish their causes and consequences.
- The development of risk models to quantify the causes and consequences of freight train derailment accidents.
- The development of cost-benefit models to enable economic indicators of each measure's efficiency to be established.
- The identification of other advantages or drawbacks for each measure thus allowing a final consideration of the most promising measures to be made.

## 0.4 Study Conclusions

### 0.4.1 Opening Remarks and Context

It is important to clarify that this report looks at the ***potential for improvement***, and is not an absolute assessment of the efficiency of all measures that are applied today. Therefore it follows that if a measure is applied extensively already there is little room for improvement through the further application of that measure. For this reason some measures that are extensively applied already are not considered in this work. Their omission should not be considered as suggesting such measures are not efficient.

In this context the measures listed in this section can be seen as efficient in addressing the potential reduction in risks associated with freight train derailments and providing the detailed background against which public policy can be formulated.

The assessment of measures does not consider the way or the order in which these interventions should be pursued, for example it is not considered whether these interventions should be introduced in a mandatory or voluntary way or whether the measure should be introduced as an EU harmonised measures or only within certain member states or only certain companies.

### 0.4.2 Efficiency Assessment of Measures

#### 0.4.2.1 Technical Preventative Measures

We consider the following technical measures as being efficient (they have a positive or unity benefit / cost ratio in our reference case and all sensitivity studies):

- P13-Wheel Load Impact Detectors / Weighing In Motion (a measure that addresses a number of common freight train derailment causes such as wheel defects, loading anomalies).
- P28-Replacement of Brass for Polyamide Roller Cages (a measure that addresses hot axle box caused freight train derailments).

- P15-Bogie Hunting Detectors (a measure that addresses problems associated with lateral instability, caused by wheel or other defects).
- P11-Bearing Acoustic Monitoring (a measure that addresses hot axle box caused freight train derailments).

Considering measure P28, we have considered an immediate replacement of brass for polyamide roller cages. We have also discussed an alternative option which is for the replacement of brass for polyamide roller cages at the next scheduled maintenance interval for axles / axle boxes. This is almost a zero cost option, although the benefits would take longer to materialise, and be a function of the maintenance cycle for freight wagons.

Potential drawbacks to the use of these measures (excluding measure P28) relate to the rate of false alarms. To some extent these can be overcome by the use of good alarm management processes. Further false alarms from those technical measures that are based on early defect detection are unlikely to have an immediate operational impact.

In addition the following two measures are efficient based on the parameters in our reference case:

- F7-Sliding Wheel Detectors (a measure that addresses problems associated with handbrakes which may be left on, seized axles and similar events).
- P16-Wheel Profile Detectors (a measure that addresses problems associated with wheel defects).

Potential drawbacks include false alarms as reported above. Finally, measure F7 is to the best of our knowledge a market with only a small number of suppliers. This may give rise to market advantage to existing suppliers of these systems if they were to form the basis of formal recommendation.

### 0.4.3 Technical Mitigation Measures

We consider the following mitigation measure as potentially efficient if the significant identified drawbacks could be solved:

- M1a-Derailment Detection (with automatic brake application) applied to All Freight Trains

This present assessment is fully in line with the previous assessment made by the Agency [4]. The significant drawback previously identified is confirmed by the present study and the related accident analysis. A false alarm of such a device may lead to train compression which is a contributory cause of freight train derailments (and also a significant operational disruption). In this respect we note that CSM Regulation, Annex I, point 2.5.4 states:

*For technical systems where a functional failure has credible direct potential for a catastrophic consequence, the associated risk does not have to be reduced further if the rate of that failure is less than or equal to $10^{-9}$ per operating hour.*

(Measure P1: Check rail has similar disadvantages, although this is not considered efficient by our assessment.)

Finally, we acknowledge an alternative type of derailment detection device which provides an alarm to the train driver when a derailment is suspected, but without an automatic brake application (type M1b). We are however not aware of these being available on the market (for freight application). We consider that an assessment of these devices, considering the human factors issues involved and their costs would be required before these could be formally assessed.

### 0.4.4 Organisational Measures

We note that the measures above are technical measures that are aimed at addressing, in some cases, organisational problems. Therefore we would add the following organisational and supervision items:

- F-2: Awareness Programme for Rolling Stock Maintenance. This measure may serve to address the problem of poor maintenance standards of rolling stock. This may include training that sought to concentrate on main rolling stock maintenance derailment causes (which can be extracted from our task report, [3]) and best practice. This measure may be followed by increased supervision of these parameters by NSAs to ensure that practicable risk reduction objectives are being applied.
- P-18: Track Geometry (all tracks). Although the case for improvements in this area are not conclusively made from a quantified perspective, the problem of poor track geometry (in particular track twist), and the possible requirement to improve this aspect just to maintain current performance levels (see Section 9.3.1) should be considered. This is of course an area for each IMs own management system. However a specific measure in this regard must be concerned with increased supervision of these parameters by NSAs to ensure that practicable risk reduction objectives are being applied.

The two measures above represent significant contributors to the derailment problem and organisational failures of individual IMs and RUs in fulfilling their obligations.

# Contents

# 1.0 Introduction

## 1.1 Background

In 2009 the European Railway Agency (the Agency) issued a recommendation (ERA/REC/01-2009/SAF) on a specific proposal, made by the RID Committee of Experts, for a new harmonised rule aimed at reducing the consequences of freight train derailments, potentially involving dangerous goods (DGs). The recommendation concerned the potential use of a Derailment Detection Devices (DDD[2]). This device automatically applies the brakes on a freight train when a derailment of a wagon equipped with that device is suspected.

Although the Agency's recommendation was that the DDD should not be adopted in the RID, the joint meeting of RISC and Inland TDG EU regulatory committees agreed that considering the low potential benefit in terms of avoided fatalities and injuries expected with DDD type devices, as well as some other problems related to the operation of trains equipped with these types of detectors, more efficient prevention measures should be further explored before deciding on imposing, by law, measures based on derailment detection.

Therefore recognising that freight train derailments remain a safety and operational concern, and following a request made by the above mentioned EU Committees, the Agency has commissioned further work the objective of which is to carry out an exhaustive analysis of all prevention and mitigation measures which could reduce the risks related to freight train derailments.

Det Norske Veritas (DNV) was selected to deliver this work, the results of which are presented in this and related documents.

## 1.2 Overall Project Scope and Objectives

The study is divided into two distinct research stages: Parts A and B.

Part A had the objective of identifying all prevention and mitigation measures that exist today or could be implemented within the short term (before 1st of January 2013) or medium term (ready to be applied or to be introduced in EU regulation within 5 to 10 years). This has been achieved through the following schedule of activities:

- Task A.1 - identification of existing operational and technical measures.
- Task A.2 - description of the markets and technologies covered by the devices/systems in use or which may be used at the short or medium term.
- Task A.3 - description of the rules (including specific devices/systems used) in generic functional and performance terms.
- Task A.4 - advice on innovative longer term measures (unlikely to be available within 10 years) which might be considered in a future R&D project.

Part B had the objective of analysing the measures identified in Part A (excluding those identified in Task A.4) with a view to identifying those that are the most efficient. Part B was scoped to include all prevention measures but limited to mitigation measures based on derailment detection.

[2] DDD is an acronym used to refer to a type of detector which automatically activates train brakes when a derailment is detected based on detection of wagon acceleration. Device type EDT-101 is an example of such a device.

Part B objectives have been achieved through the following schedule of activities:

- Task B.1 – construction of detailed fault and event trees[3] describing freight train derailments and showing which derailment cause or impact the identified safety functions act on.
- Task B.2 - semi-quantitative assessment of benefits and drawbacks of existing safety rules, and of new or improved measures at short and medium terms, using data on actual/targeted performance as well as conservative assumptions.
- Task B.3 - top ten ranking of potentially efficient new safety measures or improvements at short and medium terms, including practical and legal implementation aspects.

The geographical scope for this work is the EU-27 countries plus the 3 candidate countries, Norway and Switzerland (hereafter called the target countries). In addition, the USA and Japan are considered in the scope of safety measure identification, but limited to the most commonly used safety measures and to the foreseeable innovations at medium term. For Part B however, our measures are assessed on the basis of their potential implementation in the EU railway system only.

[3] The technical scope excludes intentional acts and derailments during civil works. Marshalling operation incidents are also excluded as the impacts arising from such events are normally more limited than from train operation. Collisions leading to derailment are also excluded from the study scope; however consequences of collisions that occur pursuant to a derailment are included.

## 2.0 Project Abbreviations and Definitions Used

| Term | Description |
|---|---|
| (the) Agency | European Railway Agency |
| CSI | Common Safety Indicator |
| CSM | Common Safety Method |
| CST | Common Safety Target |
| DDD | Derailment Detection Device of a type similar to EDT 101 |
| DG | Dangerous Goods |
| DNV | Det Norske Veritas |
| Effectiveness | The extent to which options (measures) achieve the objectives of the proposal |
| Efficiency | The extent to which objectives can be achieved for a given level of resources/at least cost (cost-effectiveness) |
| EVIC | European Visual Inspection Catalogue |
| HS | High speed (>40km/h) |
| IM | Infrastructure Manager |
| Immediately Severe | A derailment with a mechanical impact that may cause a leak or material from a Dangerous Goods wagon. |
| JSSG | Joint Sector Support Group |
| Long Term | Measures that are unlikely to able to be introduced before 10 years |
| LS | Low speed (40km/h or less) |
| Measure | A control that may be put in place to either reduce the likelihood or minimise the consequence of a freight train derailment |
| Medium Term | Measures that could be introduced within 5 to 10 years |
| NDT | Non Destructive Testing |
| NSA | National Safety Authority |
| RAM | Reliability, Availability and Maintainability |
| RID | Regulations Concerning the International Carriage of Dangerous Goods by Rail |
| RIV | Regolamento Internazionale Veicoli |
| RU | Railway Undertaking |
| Short Term | Measures that could be introduced before 1st of January 2013 |
| SMS | Safety Management System |
| Target countries | EU-27 countries plus the 3 candidate countries (Turkey, Macedonia and Croatia), Norway and Switzerland |
| TDG | Transport of Dangerous Good Regulations |
| TSI | Technical Specification for Interoperability |
| UIC | International Union of Railways |

# 3.0 Methodology and Preparatory Work

## 3.1 Summary

A fuller specification for task B.3, [1], is provided below:

> *"The task B.3 will propose a justified list of top ten potentially most efficient[4] new or improved measures on the basis of the task B.2 (efficiency assessment), the legal feasibility and the implementation costs. Both, possibilities for new or improved harmonized EU regulation, or improvements at National level (regulatory) or at Company level (voluntary) should be considered."*

The achievement of the objectives of this task represents the culmination of previous work completed in Parts A.1 to A.3 and Parts B.1 and B.2, together with some targeted and specific new work to enable the "top ten" measures to be identified.

We report on the former in Section 3.2, and the new work completed for this task in Section 3.3 and onwards within this document. We have summarised the linkages and task activities in the figure below.

## 3.2 Key Activities from Previous Project Tasks

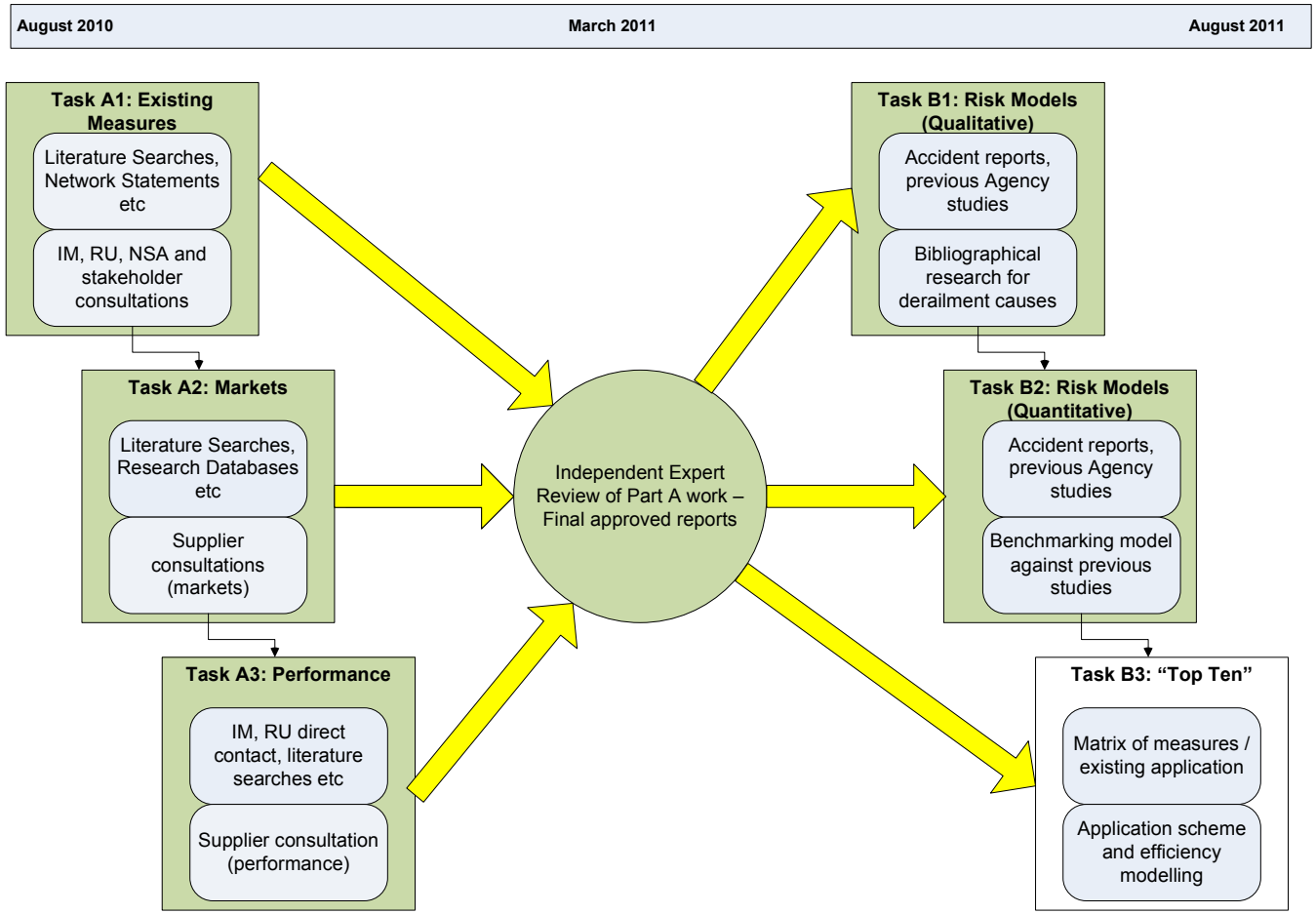
The following represents a brief summary of some of the completed key project activities:

1. For task A.1 an extensive series of consultations with Infrastructure Managers (IMs), Railway Undertakings (RUs) and other actors [2] was conducted with the objective of establishing the range of existing measures (and potentially new measures) used as controls against freight train derailments.
2. For tasks A.2 and A.3 an extensive series of consultations with suppliers was conducted regarding existing technical measures (and potentially new measures), market share, costs and benefits, [2].
3. For Task B.1 and B.2 a comprehensive accident analysis and research activity was completed to enable a risk model to be developed linking together freight train derailment causes, consequences and impacts [3].
4. A benchmarking activity was completed [3, Section 7] to compare the results of our analytical models with previous model outputs, to provide validity to our findings.

Work completed is shown shaded green in Figure 1 below. In Section 6.0 we take the opportunity to summarise the main components of these activities in relation to the cost model, although the reader is referred to the referenced documentation for more comprehensive discussion of these tasks:

[4] Efficiency refers to the consideration of costs and benefits

## Figure 1 Task Linkages[5]




[5] IM = Infrastructure Manager; RU = Railway Undertaking; NSA = National Safety Authority

## 3.3 Task B.3 Research

Specific activities for this final project task has included:

1. An activity to sort our measures into assessment categories; namely those that can be assessed quantitatively (through the use of cost / benefit modelling techniques), those that can be assessed on a qualitative basis and those that can be rejected without any form of further detailed analysis.
2. Research to provide a more complete understanding of the extent to which existing measures are used within the target countries and therefore a potential application scope for new measures, or for the increased coverage of existing measures.
3. Collection of remaining information to enable each measure's efficiency to be calculated.
4. Establishing the most efficient "top ten" with consideration to both quantitatively and qualitatively assessed measures.
5. The consideration of other factors that may influence the selection of these measures, including[6]:
    - Market considerations and whether the potential recommendation of a measure may give a supplier(s) a competitive advantage.
    - Potential drawbacks with the measure.
    - Any other issues identified during the analysis.

[6] Implementation costs are considered in the cost benefit analysis or in the qualitative assessment as documented for that measure.

## 4.0 Assessment Categorisation

The measures we have identified as part of our Part A activities are assessed as described in Table 1 (for preventative measures) and Table 2 (for mitigation measures). For these we have applied the following general scheme to determine our assessment methodology:

- Measures which have previously been ***discarded or are out of scope*** are referenced in the table below with a reference to that part of our analysis where this was agreed.
- For measures that are not discarded, we have considered how best to assess them.
    - We have used ***qualitative basis*** for assessment if the following applies:
        - They generally offer only small benefit in comparison with other measures, and / or;
        - They form part of a suite or measures that can be integrated together (for example a number of measures identified associated with rolling stock maintenance which can be integrated into a single measure), and / or;
        - There is insufficient data to enable a more detailed assessment and therefore there would be significant uncertainty in the results.
- Otherwise, measures are assessed on a ***quantified basis***.

**Table 1 Assessment Method for Preventative Measures**

| Measure Number | Description | Time Category | Efficiency Assessment? |
|---|---|---|---|
| P-1 | Check rail in sharp curves (radius less than 250 metres) | Medium | We have established parameters to enable a quantified assessment. This is reported in Section 5.2.1 |
| P-2 | Track and flange lubrication (installed on track) | Medium | We have established parameters to enable a quantified assessment. This is reported in Section 5.2.2 |
| P-3 to P-5 | Measure number no longer used. | | These measures are related to collision events, where derailment is a secondary consequence. They have not been considered further |
| P-6 | Geo radars | Medium | This measure was considered to have a commercial benefit rather than a direct derailment reduction benefit and has not been considered further. Ref [3]. |
| P-7 | Rolling stock mounted equipment for monitoring of rail profile conditions. | Medium | This measure was considered to have a commercial benefit rather than a direct derailment reduction benefit and has not been considered further. Ref [3]. |
| P-8 | Track circuit | Medium | This measure is primarily for train detection purposes and has not been considered further. Ref [3]. |
| P-9 | Interlocking of points operation while track is occupied. | Medium | This is a relatively low frequency / low severity contributor to freight train derailments. We have undertaken a qualitative assessment for this measure in Section 9.1.1 |
| P-10<br><br>P-12 | Hot axle box (hot bearing) detectors.<br><br>Hot wheel and hot brake detectors. | Medium | We have established parameters to enable a quantified assessment. This is reported in Section 5.2.3<br><br>These devices are assessed together as they are often part of the same detection system. |
| P-11 | Acoustic bearing monitoring equipment | Medium | We have established parameters to enable a quantified assessment. This is reported in Section 5.2.4 |
| P-13 | Wheel load and wheel impact load detectors | Medium | We have established parameters to enable a quantified assessment. This is reported in Section 5.2.5 |

| Measure Number | Description | Time Category | Efficiency Assessment? |
|---|---|---|---|
| P-14 | Dragging object and derailment detectors | Medium | Dragging objects are a low contributor to freight train derailment. Derailment detectors are assessed at M1. Not considered further, Ref [3]. |
| P-15 | Bogie performance monitoring / Bogie lateral instability detection (bogie hunting) | Medium | We have established parameters to enable a quantified assessment. This is reported in Section 5.2.6 |
| P-16 | Wheel profile measurement system / Wheel profile monitoring unit | Medium | We have established parameters to enable a quantified assessment. This is reported in Section 5.2.7 |
| P-17 | Measure number no longer used. | | These measures related to collision events, where derailment is a secondary consequence. They have not been considered further |
| P-18 | Sufficient availability of maintenance resources (for Infrastructure maintenance) | Short | We have established parameters to enable a quantified assessment. This is reported in Section 5.4.2 |
| P-19 | Clearance of obstructions from flange groove (particularly at level crossings) | Short | We have established parameters to enable a quantified assessment. This is reported in Section 5.4.1 |
| P-20 | Ultrasonic rail inspection | Short | Rail brakes/ruptures are relatively low frequency contributors to freight train derailments. We have undertaken a qualitative assessment / discussion for this measure in Section 9.1.2 |
| P-21 | Track geometry measurement of all tracks | Short | Addressed with P-18 above. |
| P-22 | EU-wide intervention/action limits for track twist | Medium | We have undertaken a qualitative assessment for these measures in Section 9.3.1 |
| P-23 | EU-wide intervention/action limits for track gauge variations | Medium | |
| P-24 | EU-wide intervention/action limits for cant variations | Medium | |
| P-25 | EU-wide intervention/action limits for height variations and cyclic tops | Medium | |
| P-26 | Flange lubrication - locomotives | Medium | This measure is primarily for wear reduction purposes and has not been considered further. Ref [3]. |
| P-27 | Replace composite wheels with monoblock wheels | Medium | Insufficient data to enable the measure to be quantified. Ref [3]. |
| P-28 | Replace metal roller cages in axle bearings by polyamide roller cages. | Medium | We have established parameters to enable a quantified assessment. This is reported in Section 5.3.1 |
| P-29 | Replace existing axles for stronger axles or axles with improved material properties with regard to crack initiation and crack propagation | Medium | Currently the subject of an on-going work programme (EURAXLES). Not assessed by this project. Ref [3]. |

| Measure Number | Description | Time Category | Efficiency Assessment? |
|---|---|---|---|
| P-30 | Increase the use of central couplers between wagons in fixed whole train operation | Long | Probably limited to bulk material block train on set routes. Cost of this measure significant compared to benefit. Not assessed by this project. Ref [3]. |
| P-31 | Increase the use of bogie wagons instead of multiple single axle wagons with a long wheel basis. | Medium | Potential benefit considered relatively small compared to the cost of implementation. Significant commercial issues. Not assessed by this project. Ref [3]. |
| P-32 | Install disc brakes instead of wheel tread brakes for new wagons. | Medium | The primary objective for this measure is likely to be in relation to the Noise TSI. Whilst it may have secondary benefits in terms of reduced heat activation of wheels, potentially reducing wheel failure rates, it is not considered there is a strong enough correlation between this measure and a reduced derailment rate to justify its consideration as a freight train derailment measure. Also, other measures are in place, or could be put in place, which would be more effective against this potential derailment hazard. |
| P-33 | Rolling stock design for track twists (for new wagons) | Long | The time for this measure to be implemented is governed by the renewal rate of wagons. Not likely to be possible before the long term, and hence not considered by this project. Ref [3]. |
| P-34 | Secure underframe brake gear from falling down | Medium | Brake gear or other wagon underframe gear that can fall down and cause derailment is in many countries prevented by the use of safety slings. Although a wider application of this measure may have potential benefit, we note that this a relatively low frequency contributor to freight train derailments. We have undertaken a qualitative assessment for this measure in Section 9.1.3 |
| P-35 | Regular greasing and checks of rolling stock buffers. | Short | This is assessed on a qualitative basis in conjunction with measure F-2 in Section 9.3.2 |
| P-36 | Wheel set integrity inspection (ultrasonic) programs. | Short | This is assessed on a qualitative basis in conjunction with measure F-2 in Section 9.3.2 |
| P-37 | Derating of allowable axle loads | Short | Currently the subject of an on-going work programme of the Joint Sector Service group. Not assessed by this project. Ref [3]. |
| P-38 | EVIC (European Visual Inspection Catalogue)-based inspection of freight train rolling stock axles | Short | Currently the subject of an on-going work programme through EVIC. Not assessed by this project. Ref [3]. |
| P-39 | Double check and signing of safety-classified maintenance operations | Short | This is assessed on a qualitative basis in conjunction with measure F-2 in Section 9.3.2 |
| P-40 | Qualified and registered person responsible for loading | Medium | This is assessed on a qualitative basis in conjunction with measure F-2 in Section 9.2.1 |
| P-41 | Locomotive and first wagons of long freight trains in brake position G | Short | This is assessed on a qualitative basis in Section 9.2.2 |
| P-42 | Limitations on use of brake action in difficult track geometry | Short | This is assessed on a qualitative basis in Section 9.2.2 |
| P-43 | Dynamic brake test on the route | Medium | This is assessed on a qualitative basis in Section 9.2.3. |
| P-44 | Saw tooth braking to limit heat exposure to wheels | Short | This measure is assumed to be applied where it is required and is not assessed by this project. Ref [3]. |

| Measure Number | Description | Time Category | Efficiency Assessment? |
|---|---|---|---|
| P-45 | Initiation of braking or speed reduction prior to passing signal showing reduced speed | Short | We consider this to be part of existing driver practice and therefore implemented where required and is not assessed by this project. Ref [3]. |
| P-46 | Not allowing traffic controllers and drivers to override detector alarms | Short | This is assessed on a qualitative basis in Section 9.2.4. |
| P-47 | Wagons equipped with a balance to detect overload in visual inspection. | Medium | This is assessed on a qualitative basis in Section 9.2.5. |
| F-1 | End of train device (brakes) | Medium | Not considered to have substantial benefit for existing freight train lengths. Not assessed by this project. Ref [3]. |
| F-2 | Awareness program and improved maintenance for Rolling Stock | Short | This is assessed on a qualitative basis in Section 9.3.2 |
| F-3 | Heat sensitive material to reveal hot axle box conditions | Short | Not considered further, [3]. However we note that this measure could have a role to play to aid in separating false alarms from genuine alarms. |
| F-4 | Machine Vision Devices | Medium | We do not believe we can make an assessment of systems of this type when solely deployed as a freight train derailment prevention system.<br>Systems of this type are built around a core module with options that may include:<br>• 3D Profiling (for out-of-gauge loads)<br>• Fire detection functions<br>• Pantograph defects detection<br>• Wheel load measurement<br>• Thermographic mapping<br>In the context of a holistic accident prevention system, this technology may prove cost-effective. However, the functionality in relation to derailment prevention (wheel load, hot axle box detection etc) is already addressed.<br>Systems of this type may detect potential derailment causes that are not covered by the systems studied to date – such as open hatches or covers that may become detached and pose a derailment risk – however it is inconceivable that a network of machine vision devices consisting of a core module and profile measurement module would be deployed for this purpose.<br>We have not considered this further. |
| F-5 | Telematics | Medium | This measure does not have a direct impact on derailment rate. Not assessed by this project. Ref [3]. |
| F-6 | Anti-lock devices | Medium | Quantified assessment |
| F-7 | Sliding wheel detectors. | Medium | Quantified assessment |
| F-8 | Handbrake interlock. | Medium | We consider this to be similar F-6 and F-7. This measure is not assessed. |

## Table 2 Assessment Method for Mitigation Measures

| Measure Number | Description | Time Category | Efficiency Assessment Method |
|---|---|---|---|
| M-1a | | Medium | Quantified assessment |
| M-1b | | Medium | Quantified assessment |
| M-2 | Equip tank wagons with impact shielding to protect against penetration | | No. This is outside the scope of work covered by this project. |
| M-3 | Install emergency warning lights on locomotive to warn train on neighbouring track going in opposite direction of derailment | | No. This is outside the scope of work covered by this project. |
| M-4 | Attach mechanical guides to the bogie structure or on wagon at an appropriate position so that is more likely that the derailed wagon is kept on the track and does not overturn. | | No. This is outside the scope of work covered by this project. |
| M-5 | Install safety rails (guard rails) at bridges and in tunnels | | No. This is outside the scope of work covered by this project. |
| M-6 | Install battering rams in front of safety critical pillar supports of roof structures and overbridges in order to prevent derailed rolling stock damaging such safety critical structures | | No. This is outside the scope of work covered by this project. |
| M-7 | Installation of dragging object and derailment detectors | | No. This is outside the scope of work covered by this project. |
| M-8 | Installation of deviation points leading to a safe derailment place in strongly descending tracks from marshalling yards and train formation stations | | No. This is outside the scope of work covered by this project. |
| M-9 | Radio or cell phone communication installations like GSM-R in order to transfer emergency stop orders to trains | | No. This is outside the scope of work covered by this project. |
| M-10 | Separate passenger and freight traffic to separate lines to a larger degree (which is also EU-policy) | | No. This is outside the scope of work covered by this project. |
| M-11 | Restrictions on freight traffic in general or hazardous materials transport in special through certain busy passenger terminals and/or underground stations to restrict traffic and limit the consequences of a derailment. | | No. This is outside the scope of work covered by this project. |
| M-12 | Develop and apply a checklist for dangerous goods transport as the Swiss checklist for dangerous goods transport by freight trains | | No. This is outside the scope of work covered by this project. |
| F-9 | Harmless infrastructure | | No. This is outside the scope of work covered by this project. |

# 5.0 Quantified Assessment Parameters and the Cost Model

## 5.1 General Assumptions and Clarifications

The following assumptions apply to the measures discussed below:

1. Some technical measures discussed in this section may benefit from trending. This trending can increase the effectiveness of such measures. These types of measures work on single inspection / pass-by, but their effectiveness is generally lower in this set-up. The trending function requires each wagon to be fitted with some form of telematics or wagon "tagging". The costs of such technology are not included in the assessment of derailment prevention measures.
2. The application scopes we discuss below are indicative based on suppliers' recommendations and other information. In practice, each IM or RU would need to consider an application scope that best achieved the objectives.
3. We note that some countries have invested heavily in some of the measures, whilst others may have chosen different options. We have not considered a per-country application scope taking this into account. Our analysis is therefore to be taken as a European average picture.
4. We consider each measure in isolation on its individual merits in terms of preventing or mitigating freight train derailments. Combinational measures are not considered. We have provided some commentary on combinational issues at Section 10.2.
5. Non-safety benefits (such as reduced maintenance costs, increased asset lifetime) are not considered.
6. Track length in the EU-27 is approximately 340,000 km (extracted from Eurostat, "Railway transport – Length of Tracks" and from DNV consultation), 85% of which is open for freight traffic (estimated from DNV consultation). Freight traffic therefore operates on approximately 289,000 km of track.
7. We have assumed an additional 10% for side-tracks in stations and yards, hence 34,000 km (all of which we assume can be operated by freight traffic).
8. We are aware that recent developments directed towards specific derailment causes (such as hot axle box derailments) will reduce the future benefit available, compared with the historical average. We discuss this in the relevant sections below.

## 5.2 Infrastructure Measures

### 5.2.1 Measure P-1: Check Rails

#### 5.2.1.1 Measure Objective

Check rails are installed to guide the wheels in rigid crossings and point crossings. Check rails may also be installed in sharp curves to prevent derailments as it will hinder flange climbing on the outer rail in sharp curves. In some countries check rails may also be used to give additional safety against derailment when the track is passing safety critical installations such as overhead bridge supports. It is the application in sharp curves we consider here.

#### 5.2.1.2 Measure Installation Scope

For this measure to be effective check rails would be installed in curves of radius less than 250 metres on all routes where freight may be carried (where not currently fitted). Information regarding the quantity of such locations within the European rail community is not available to

the project team, and would require each IM to survey their network to determine suitable locations. In the absence of this information we have made the following assumptions:

- Applicable total track length for this measure is assumed to be (289,000 + 34,000) = 323,000 km.
- Our knowledge of track layout in Norway (as a reference example) indicates that in the region of 1% to 2% of the network open for freight traffic is made up of curves of this type. However, Norway has a "curvy" network and the average in the EU-27 is likely to be less than this. Further, some curves are fitted with check-rails, although not a significant number. Taking these factors into consideration we have chosen a reference value of 0.5% for track length satisfying our criteria. Applying these factors, we use a value of 323,000 km * 0.5% = 1,615 km.
- A more limited application scope may be possible. This may be for high usage freight routes on curvy lines or other "at-risk" sections, where alternative approaches (such as track lubrication or cant adjustment) are not feasible. However, detail on the extent of the EU-27 network that satisfies this requirement is not known and therefore not assessed.

#### 5.2.1.3 Measure Effectiveness

In terms of a maximum potential benefit we reported 25 avoided derailments [3] to be possible and achievable with a comprehensive application scope (similar to that described above), if the measure could be 100% effective.

In [2] we assigned this measure an effectiveness of 90% which we would consider to be an appropriate reference value.

### 5.2.2 Measure P-2: Track Lubrication

#### 5.2.2.1 Measure Objective

Lubrication of the flange and track contact point is an important measure in reducing the friction between rail and wheel flange and hence reduce the risk of derailment in difficult track geometries, i.e. in narrow curves or track sections with high cant and/or high twist. The reduced lateral track force in narrow curves should cause less wear, less noise and less risk of derailment.

#### 5.2.2.2 Measure Installation Scope

In many countries traction unit based flange lubrication is an applied measure addressing this problem for regularly used routes. The major benefit from track lubrication units is in countries where flange lubrication measures are not frequently used, and for parts of the network that are not regularly operated (e.g. side-tracks which are common derailment locations).

Knowledge of each IMs network and the proliferation of side-tracks and their usage pattern is not available to the project team. In the absence of this information we have made the following assumptions:

- Side-tracks are installed approximately every 15 km of track length.
- 50% of side-tracks are infrequently used (and may have dry rails) or are otherwise at a lower level of repair than main-line routes.
- One or two lubrication units are required per side-track, depending on conditions. We have used an average of 1.5 per side-track.
- The required number of units is estimated at (289,000 / 15) * 1.5 * 50% = 14,450.

#### 5.2.2.3 Measure Effectiveness

The effectiveness for this measure is somewhat difficult to estimate. In this respect we are not aware of any study that has been performed that quantifies lubrication effectiveness as a derailment mitigation option (we have contacted many suppliers on this subject, and they are also not aware of such studies). However, it is frequently referenced as a "good measure" and often recommended in accident reports as a measure that should be applied.

We have made a working assumption that it may be up to 50% effective in cases where dry rail has been a contributory derailment cause. This is applied to the maximum number of potentially avoided derailments for this measure, which we reported to be 25 [3].

### 5.2.3 Measure P-10 and P-12: Hot Axle Box / Hot Wheel and Brake Detectors (HABD/HWD)

#### 5.2.3.1 Measure Objective

Hot axle boxes leading to axle journal seizures and ruptures are amongst the most frequent cause of freight train derailments, and also have a tendency to occur at high speeds, [3]. In response to this many IMs have taken steps to install hot axle box detectors, with recent activity to increase the coverage and replace older designs with newer technical solutions. Further, some countries that currently have no such devices are embarking on an implementation strategy [4]. In this context we estimated in our market assessment [2] approximately 1,500 units currently in use; a number which we believe to be increasing.

#### 5.2.3.2 Measure Installation Scope

In terms of current installations, of the 1500 units we estimated to be in use, some will be "double units" covering adjacent lines. For the basis of our assessment we have assumed 50% to be double units, therefore:

- Coverage = 289,000[7] km / (1,500 * 1.5 * 85%[8]) = 151 km between installations.
- Coverage of one per 50 km (a typical installation density, although we do note that hot axle box derailments can occur less than 50 km from the last operational hot axle box detector) would require approximately 5,780 units installed in total, therefore a further 3,530 units.

#### 5.2.3.3 Measure Effectiveness

The recent developments in terms of increased installation density and improved technology discussed in Section 5.2.3.1 is likely to make significant in-roads towards reducing derailments caused by hot axle boxes and related causes. (One IM has stated that they have reduced to almost zero the incidence of derailments caused by hot axle boxes / broken axles and broken wheels, partly as a result of implementing this technology – of course with suitable supporting arrangements such as the availability of side-tracks and a robust alarm management process.)

We therefore need to address the fact that solutions currently being implemented are likely to return benefits in future years, regardless of any additional action that may be taken. In this regard we have made the following working assumptions:

- The data used for our accident analysis is an average assessment based on previous years' accident figures. In this regard our accident data is "lagging" current figures and does not take into the developments discussed above. In particular the increasing use of HABD/HWD in recent years will have the effect of reducing the available benefit for measures directed towards derailments from that cause. In this respect we have assumed our data is lagging by at least 1.5 years, and that by 2013 will be a further 1.5 years behind.

[7] We exclude side-tracks from the installation scope for these measures
[8] We have assumed that of the total HABD installations, they are equally distributed on mixed, freight only and passenger lines. Hence the 85% of them will be installed on freight carrying routes.

To compensate for this we have applied the assumption (used in [3]) that a 6% year-on-year reduction of derailment rate and therefore the available benefit, should be applied[9]. Starting from our maximum risk reduction potential of 80 avoided derailments per year [3]; we arrive at a revised maximum potential benefit of 67 avoided derailments per year.

- We note from our accident analysis [3] that at least 10% of hot axle box derailments occur despite the incident train having previously passed a HABD/HWD. This is an underestimate of the true position since we only count cases where this has been explicitly stated. (In Germany, where the most HABD/HWD are installed, we observe the highest proportion of derailments due to hot axle boxes.) We assume 10% of such failures will continue to evade detection, even with a comprehensive application scope.
- Applying this we deduce that a revised maximum risk reduction potential is 60 avoided derailments.

### 5.2.4 Measure P-11: Acoustic Bearing Monitoring (Bearing Acoustic Monitoring; BAM)

#### 5.2.4.1 Measure Objective

Acoustic bearing detectors are, like HABD, used to detect developing mechanical structural defects associated with wheel bearings. They are however based on the analysis of sound as wheel sets pass by. The major advantage over HABD is that acoustic bearing detectors are able to detect developing defects much earlier as such defects will result in increased noise. It is stated by one supplier that defects can be detected 10,000's of km before a failure occurs. Trending over time allows early identification of defects before they lead to failures.

#### 5.2.4.2 Measure Installation Scope

We use the following assumptions:

- Suppliers' recommended 30 units per 50,000 km of track are installed. Hence a density of (289,000 / 50,000 * 30) = 173 units would be required. However, we note that this is mainly in relation to long haul routes in the USA and Australia. For short / medium haul routes (of say 100 km to 300 km) it is possible that a BAM would not be encountered very frequently / at all if installed at this density. (Although the significant advance warning stated for this measure does not require a freight train to pass a detector site very frequently.) We have calculated that one detector installation per 500 km or track would be necessary in Norway to cover approximately 95% of freight train operations, and consider this would be a suitable indicative installation density for European application, hence about 578 units. There are few installations existing in the EU (other than test locations), hence these would be new.

#### 5.2.4.3 Measure Effectiveness

In terms of benefit and effectiveness:

- Maximum available benefit 63 avoided derailments per year [3] reduced by 6% per year as reported for HABD. This suggests a maximum achievable benefit of 53 avoided derailments per year.
- It is stated by one supplier that BAM are 90% effective in detecting the early on-set of bearing problems on a single pass-by, and that this increases to 95% when trended. It is also stated that the technology can detect defects in brass or polyamide roller cages equally as reliably[10].

[9] We have applied the 6% factor to the derailment causes that we believe to be reducing; this does not apply to all derailment causes so it is not applied to all measures.
[10] These are supplier claims which we are unable to validate due to lack of EU experience.

### 5.2.5 Measure P-13: Wheel Load and Wheel Load Impact Detectors (WLID) / Weighing In Motion (WIM)

#### 5.2.5.1 Measure Objective

Devices of this type typically monitor rail vehicle wheels for rolling wheel surface defects such as flats and spalls, together with wheel out of roundness and vehicle weight imbalances. They may help to detect wheel defects and also identify conditions that may, if left un-rectified, lead to wheel-set failures.

#### 5.2.5.2 Measure Installation Scope

Considering the information we have assembled:

- An installation density of approximately one unit per 1000 km is suggested, thereby indicating a fully covered installed base in the EU of (289,000 km / 1000 km) = 289 units. (Installation locations are likely to be where a freight train can be inspected and removed from service, or denied access to the network.) However, as we have reported for BAM, this is unlikely to provide full coverage for all freight traffic and we note that the Netherlands has an average installation density of about one unit per 170 track km (in the Netherlands this technology is used for track access charging in addition to derailment mitigation). We have assumed a targeted and planned installation density of one unit per 500 track km would provide a reasonably comprehensive coverage for most freight traffic, hence about 578 units.
- We estimated a total of 150 current installations [2], with 85% on freight traffic routes, hence 128 units. A further 450 units would therefore be required for a comprehensive coverage.

#### 5.2.5.3 Measure Effectiveness

In terms of potential benefits and effectiveness, the following may be summarised:

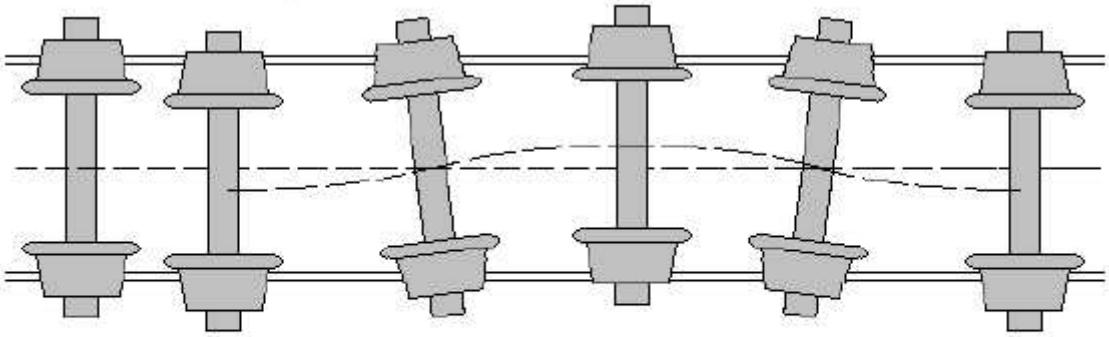
- We indicated a maximum potential benefit of 120 avoided derailments. This is modified by the observed 6% year-on-year reported for HABD, hence 100 avoided derailments.
- We note that the Netherlands [4] is quoted as indicating a 90% reduction in hot axle box failures, as well as significant reductions in derailments by other causes (for example broken primary suspension reduced by almost 100%), following the application of this technology. Although the Netherlands uses relatively few HABD, it is considered likely that the combinational effect of these two technologies (as well as other factors) has resulted in this dramatic reduction in reducing hot axle box and other derailments. For the purpose of our modelling activity, we have assumed 75% effectiveness for this measure in isolation.

### 5.2.6 P-15: Bogie Performance Monitoring / Bogie Lateral Instability Detection (bogie hunting)

#### 5.2.6.1 Measure Objective

This wayside defect detection system is capable of detecting and identifying wagon bogies that exhibit poor steering performance, an example of which is shown below. Bogie hunting is likely to occur when the rail profile is worn outside of allowable conditions; a wheel profile detector is likely to offer similar functionality.

**Figure 2: Lateral Instability**



This system monitors safety performance in several dimensions such as: potential of flange climb derailment, gauge spreading, and rail over. Like BAM, devices of this type often rely on trending to enable defects to be identified and early maintenance action scheduled to correct the defect.

5.2.6.2 Measure Installation Scope

In terms of application:

- We have assumed that a similar coverage as BAM, hence a density of 578 units. There are few installations existing in the EU (other than test locations) therefore these would mostly be new installations.

5.2.6.3 Measure Effectiveness

In terms of benefit and effectiveness:

- We estimated a maximum available benefit of 47 avoided derailments per year [3]. This is not modified by our 6% reduction factor as derailments from this cause are not considered to be addressed by the recent programmes to reduce the frequency of hot axle box derailments.
- Little data exists in the countries that are within the scope of this study relating to the effectiveness of these measures, because they are not installed to any great extent. By virtue of the fact that they are installed in the USA, Australia and other geographies, we assume they are effective. We have used a 90% effectiveness rating for this measure.

5.2.7 P-16: Wheel Profile Monitoring System / Wheel Profile Monitoring Unit

5.2.7.1 Measure Objective

Damage to the wheel profile may be a contributing cause to derailments. Whereas wheel load impact detectors can detect some wheel profile problems, wheel profile measurement systems provide a more complete picture. They are also based on other technology: analysis of wayside digital camera images highlighting the profile using lasers or strobe light. A number of wheel profile parameters are captured, e.g. flange height, flange width, flange slope, tread hollow and rim thickness. Some measurement systems can operate with trains passing at high speeds (e.g. up to 140 km/h).

5.2.7.2 Measure Installation Scope

This type of unit would be installed where the widest coverage could be secured; this may include at major depots and selected freight routes across the network. It would not be

required that freight trains / wagons were required to pass a detector site frequently, as defects evolve over time and are unlikely to be immediately catastrophic.

Considering the information we have assembled and our comparison of this technology with bogie hunting detectors:

- An installation density of one unit per 500 km, hence about 578 units.
- For the purpose of our assessment we estimate 30 current installations [2], with 85% on freight traffic routes, hence 26 units. A further 548 units would be required using this as a basis. (Installation locations are likely to be where a freight train can be inspected and removed from service, or denied access to the network.)

#### 5.2.7.3 Measure Effectiveness

In terms of potential benefits and effectiveness, the following may be summarised:

- We indicated a maximum potential benefit of 23 avoided derailments. This is modified by the observed 6% year-on-year derailment reduction factor, hence 19 avoided derailments.
- We assume the effectiveness of this measure to be similar to other technical measures. An effectiveness of 90% is used.

### 5.2.8 F-7: Sliding Wheel Detectors

#### 5.2.8.1 Measure Objective

The sliding wheel detector is a mechanical device that compares wheel rotation rates between wheel sets to detect locked wheels. It may detect issues such as handbrakes that are not released, jammed wagon brakes or seized axle box bearings.

#### 5.2.8.2 Measure Installation Scope

The system is normally installed in depots and sidings on departure roads and possibly other strategic locations. Suppliers' recommendation for application in Great Britain (GB) would be for 100 units (and GB accounts for about 9% of European track length) hence about 1,100 units would be required to cover the European rail network. We are not aware of many that are currently installed; hence we consider these "new". We do consider this optimistic, and that it would probably not cover all freight origin points and strategic places en-route where locked wheels may be likely. We have increased our scope estimates by 20% to cover additional strategic points. Hence we use 1,320 units.

#### 5.2.8.3 Measure Effectiveness

Our assessment of the measures potential effectiveness is as follows:

- We indicated a maximum potential benefit of around 27 avoided derailments. On further of this this measure we conclude that it cannot be as effective as, say measure P-6: Anti-Lock devices as it cannot detect locked wheels between detection sites. Hence to provide a realistic assessment of the potential effectiveness of this measure we have undertaken a detailed review of our accident database [2, Annex 1] to specifically identify freight train derailments that can be directly attributed to this cause (UK-1 and NL-8 are examples). Through this research we consider that approximately 1% to 2% of freight train derailments have this as a cause and we have used 8 avoided derailments as our reference case.

- This measure is not applied in the EU and therefore we have no specific effectiveness data. However this is used in other countries, such as Australia. We assume that as it an existing and mature measure it is at least 90% effective.[11]

## 5.3 Rolling Stock Measures

### 5.3.1 Measure P-28: Replace Metal Roller Cages in Axle Bearings by Polyamide Roller Cages

#### 5.3.1.1 Measure Objective

Polyamide roller cages are stated to offer safety improvements compared with brass roller cages, decreasing the incidence of overheating and axle box failures. Manufacturers' claims[12] include:

- Reduced friction and wear and reduced operating temperatures.
- Safe failure mode without seizing.
- Can operate for longer periods without lubrication (testing is stated to have shown that polymer cages can operate for more than 500 km when all lubrications is removed. This is well beyond that which steel based cages can safely operate), [5].
- Compared with machined brass cages they are substantially lighter, which minimizes dynamic adverse conditions in bearings. Two sliding elements steel - polyamide have better sliding properties as compared with steel - brass. In addition to that polyamide better damps vibrations and noise. Thanks to technologic abilities the cage design has been solved to permit optimum passage of lubricant to rolling elements. Another advantage of bearings is self-lubricating capacity of polyamide. In case of lubrication deficiency the wheel set seizure does not occur so instantly as in case of brass cage bearings, [6]

It is important to note that these are suppliers' claims. However in many derailment accident reports where a hot axle box has been the cause it is specified that the bearing had a brass roller cage; in none of the accidents has it been specified that there was a polyamide roller cage. We are aware that programmes to replace brass roller cages with polyamide roller cages have been introduced by several RUs, among those:

- CargoNet in Norway in 2000
- VR in Finland pre 2003.

The replacement appears to have been effective resulting in a reduced number of hot axle box derailments although sufficient data for quantification does not exist.

Similar programmes are applied by other RUs. Since the normal maintenance interval for freight wagon roller bearings are 12 years (for brass or polyamide to the best of our knowledge) the last brass roller cage in the CargoNet owned rolling stock fleet should be removed by 2012.

#### 5.3.1.2 Measure Installation Scope

Currently a number of RUs are requiring the replacement of brass with polyamide roller cages on an opportunistic basis, to combat the significant problem of hot axle box derailments. We believe there to be little cost difference between brass and polyamide variants and hence this

[11] To be effective the wheel must be locked and skid. It may not be effective in cases where the handbrake is only partly applied as the wheel may continue to rotate.
[12] We note many manufacturers' claim benefits from the use of these roller cages, and that it also a common recommendation arising from accident reports to replace brass for polyamide roller cages. However, we have not seen any independent validation of such claims.

is a minimal cost option. We are however unable to assess this in any reasonable manner as there is no appreciable cost.

A second option would be to change all remaining brass roller cages with polyamide. We are unaware of the total number of bearings of each type in use, but we assume the following:

- 50% of the existing freight fleet are fitted with brass roller cages. There are about 720,000 freight wagons [7] with a mix of single axle and bogie wagons (equal mix assumed). This equates to upwards of 2,000,000 roller bearings requiring replacement.

#### 5.3.1.3 Measure Effectiveness

- We estimated a maximum available benefit of 53 avoided derailments per year [3] as for HABD. This is modified by the observed 6% year-on-year derailment reduction factor, hence 44 avoided derailments.
- If we are able to take the suppliers' claims at face value, then the ability to operate for lengthy distances without lubrication and excessive heat build-up (up to 500 km) and also be more tolerant of vibrations is likely to be significant. On this basis we have assumed this measure to be 75% effective[13].

(Additional benefits could be for example requiring a lesser density of installation of HABD.)

### 5.3.2 F-6: Anti-lock Devices

#### 5.3.2.1 Measure Objective

Devices of this type act to reduce locking of the wheels and associated wheel damage during braking on railway freight cars. In turn this may reduce maintenance costs of re-profiling wheel sets, increase safety with reduced risk of wheel cracking or major tread damage that could increase derailment risk, reduce impact forces to track and reduce noise.

#### 5.3.2.2 Measure Installation Scope

The large retro-fit time (up to 12 days per wagon), coupled with the limited derailment safety benefit estimated for these types of product [3], would lead us to consider this measure will be applicable to new wagons only. Therefore to consider this measure we have modelled it as if it were fitted to the entire fleet but considering only the acquisition and on-going maintenance cost (not the fitting cost).

#### 5.3.2.3 Measure Effectiveness

This measure addresses wheel failures and other derailment causes where these are caused by braking failures (including handbrakes not released, brakes remain stuck on after application etc). We predicted up to 27 derailments from this cause [3]. This measure is not modified by our 6% reduction factor as derailments from this cause are not addressed by the recent programmes to reduce the frequency of hot axle box derailments.

The device has no measured effectiveness or reliability claims, since it is new to the market. We have assumed that it will be 75% effective in preventing derailments from the causes that it seeks to mitigate.

### 5.3.3 M-1: Derailment Detection

#### 5.3.3.1 Measure Objective

There are two devices of this type: those that act directly on the brake pipe invoking a immediate and automatic full application of the brake (M-1a); those that provide a clear

[13] We would consider it prudent for independent substantiation of suppliers claims to be performed in advance of any recommendation.

indication to the train driver of a suspected derailment (M-1b) but without automatic brake application. The objective is to prevent a derailed axle causing further damage, and/or the initial derailment escalating in severity.

#### 5.3.3.2 Measure Installation Scope

Two devices are fitted per wagon within the following scope:

- All freight wagons (approximately 720,000).
- All freight wagons carrying dangerous goods (DG) (approximately 100,000).
- A sub-set of DG wagons, as proposed by RID 2013 provision (approximately 17,000).

We consider these options in our analysis. We also consider that there are about 2,000 wagons fitted with devices of this type. These are largely fitted to DG tank wagons, and we assume that 75% are fitted to tank wagons carrying the most hazardous materials as covered by the proposed RID 2013 provision (hence 1,500).

#### 5.3.3.3 Measure Effectiveness

We have studied the accident database we have assembled and are able to report the following[14]:

- There are five accidents that appear to have been initially non-severe, but the application of emergency brakes is stated to have been a contributory factor in the derailment escalating. We cannot know the outcome had emergency brakes not been applied. (Comparable with M-1a.)
- There are 62 accounts of cases where the application of emergency brakes (either through the brake pipe being severed or driver emergency braking) has occurred, and the train has been brought to a safe stop. We cannot know the outcome had emergency brakes not been applied; it is possible that the train would not have been brought to a safe stop.
- There are four cases where the driver has known or suspected a derailment but has not taken appropriate action leading to further wagons derailing. It is not known whether this further derailment led to an escalation of severity. (Comparable with M-1a.)

Given these data, it is not possible for us to conclude or differentiate between these two measures in terms of which may be the best option from a safety point of view. In the absence of information to separate the measures from an effectiveness perspective, the only parameter that we re-model (with reference to our event tree, [3]) is the detection probability. We assume that for wagons fitted with a device of this type (M-1a, M-1b) that 95% of derailments will be detected as soon as they occur.

## 5.4 Organisational Measures

### 5.4.1 Measure P-19: Clearance of Obstructions from Flange Groove (particularly at level crossings)

#### 5.4.1.1 Measure Objective

Obstructions in the flange groove may lead to freight derailments, albeit few in number. Inspection and clearance of obstructions is a measure that may address this issue.

[14] Not all accident report provide information to establish whether emergency braking was initiated, hence we are not able to include those in this analysis

#### 5.4.1.2 Measure Installation Scope

The European Level Crossing Forum report 125,000 level crossings in Europe. If we assume that 85% of these are on lines that freight traffic may use, then there are about 106,000 level crossings that fit within the scope of this study.

Some level crossings are more exposed to this hazard than others; for example urban locations where level crossings are surrounded by tarmac are perhaps less likely to get stones obstructing them, compared with rural locations. For the purposes of our assessment we have considered that most level crossings are in urban areas or are otherwise not significantly exposed to this hazard to the same extent. We have used an assumption that 25% of level crossings are exposed hence 26,500 level crossings would require additional inspection effort.

For this measure to be effective, inspections over and above the existing inspection interval would be necessary. In this regard we have assumed the following:

- That an inspection would be required after inclement weather. This would include wet weather / daytime thaw followed by freezing conditions. Strong winds that could move debris are another potential cause.
- Optimistically we have assumed that these weather conditions may occur 10 days per year, therefore additional inspections of 10 * 26,500 level crossings = 265,000 additional inspections.
- Each inspection takes 30 minutes.
- This is required on-going cost requirement.

#### 5.4.1.3 Measure Effectiveness

We have assumed this measure will be 90% effective in removing all derailments attributable to this cause.

This measure is not modified by our 6% reduction factor as derailments from this cause are not addressed by the recent programmes to reduce the frequency of hot axle box derailments.

### 5.4.2 Infrastructure Track Geometry Measures

#### 5.4.2.1 Measure Objective

Track geometry defects are one of the most common causes of freight train derailments. We have also noted that there is an increasing use of single axle wagons with a very long wheel base which makes the derailment risk in twisted track even larger and with an increased containerization as well as loading by bulk material by front wheel loader the control of skew loading is more of a challenge.

We consider this problem in relation to secondary lines predominately for freight operations, as well as side-track at stations:

We consider here the following:

- P-18: Sufficient availability of maintenance resources to maintain lines and tracks at stations and side tracks to minimum safety requirements.
- P-21: Track geometry measurement of all tracks.

Other issues such as

- P-22: EU-wide intervention/action limits for track twist.
- P-23: EU-wide intervention/action limits for track gauge variations.

- P-24: EU-wide intervention/action limits for cant variations.
- P-25: EU-wide intervention/action limits for height variations and cyclic tops.

are addressed elsewhere in our report.

#### 5.4.2.2 Cost and Application Data

There is some difficulty making a quantified assessment of measures of this type, due to data shortages and also the insistence of many IMs that they both have sufficient resources and apply appropriate standards to all their assets. This is not always borne out by accident reports. Further there are national differences in accident rates and also criteria which pose a problem for a "European average study" such as this.

We have established from [8] an average railway maintenance cost of about €25,000 per track kilometre. Further, approximately 40% of this figure is for permanent way maintenance and about 50% for track work. Hence this equates to about €5,000 (€25,000 *40% * 50%) per track kilometre. We assume this is for track geometry testing and rectification work. This figure applies to main-track.

We assume secondary lines and side-track accounts for 34,000 km. We have further assumed that a partial inspection of these is already undertaken, perhaps at an expenditure of 50% of that applied to main-track. This has two consequences:

- An annual increased maintenance cost of €2,500 per secondary line / side-track kilometre would be required to maintain to a similar level to main-track.
- In addition to the cost above, it is likely that there would likely be an initial one-off spend required to upgrade secondary line / side-track to bring it up to specification. We have made an assumption here that in year one this would amount to double the annual maintenance cost, hence €5,000 per side-track kilometre.

#### 5.4.2.3 Effectiveness Data

In our accident data we have identified that approximately 50% of derailments occur in stations / side-tracks, despite these locations accounting for 10+% or total track length. Using these approximate figures, we can postulate that:

- From the number of derailments predicted as a result of track geometry failures (129 [3]), it is theoretically possible that a 45% reduction could be achieved, to 58.
- This measure is not modified by our 6% reduction factor as derailments from this cause are not addressed by the recent programmes to reduce the frequency of hot axle box derailments.

# 6.0 The Cost Model and Parameters

## 6.1 Cost Model Summary

The cost model brings together all the facets that apply to the measures we have identified.

These are on the one hand costs associated with each measure and on the other hand the benefits that the measure may secure.

Costs of a measure include:

- The quantity (number of units, deployment rate, resource requirement etc.) for the measure.
- The costs per unit for the measure.
- Annual maintenance and upkeep other costs for measure.

Benefits include:

- The number of avoided derailments (or reduced number of severe derailments for "M" measures), each of which has benefits that include:
    - Reduction in the number of fatalities and injuries associated with freight train derailments.
    - Reduction in the quantity of damaged tracks, damaged wagons, operational disruption and environmental contamination.

It is the purpose of the cost model to weigh these factors such that the most efficient measures can be selected. To achieve this both the costs and benefits need to be monetised. The details of how this is achieved are provided in our reports [9], [3], although we recap these below.

The benefits of implementing a measure in terms of avoided derailments are monetised using the information shown below.

**Table 3 Railway System and Operational Costs[15]**

| | Track Damage | | Wagon Damage | | Disruption Costs | |
|---|---|---|---|---|---|---|
| Scenario | Average Km | Cost (E/km) | # wagons | Cost/wagon (E/wagon) | Hours disruption | Cost/hour (E/hour) |
| Immediate severe, DG involvement | 0.5 | 427746 | 7 | 23526 | 50 | 16040 |
| Not immediate severe, DG involvement | 5 | 160405 | 7 | 23526 | 50 | 16040 |
| Immediate severe, no DG involvement | 0.5 | 427746 | 7 | 12832 | 50 | 16040 |
| Not immediate severe, no DG involvement | 5 | 160405 | 7 | 12832 | 50 | 16040 |
| Not severe derailment, safe stop | 0.5 | 32081 | 2 | 5347 | 12 | 8020 |

In addition, the cost model assigns monetised benefits associated with the value of preventing a fatality or injury of €1,500,000 and €200,000 respectively.

Therefore, preventing an immediately severe DG derailment that leads to loss of three lives has a cost (at today's values) of:

- (3 * €1,500,000) + 0.5 * (€427,746) + 7 * (€23,256) + 50 * (€16,040) = €5,678,665.

An event of this type is predicted to occur at a rate that is calculated by our frequency assessment model. For example, if this is predicted to be once every ten years, then the annual cost is:

[15] A severe derailment is defined as an event with a mechanical impact that may cause a leak of material from a DG tank / wagon, or for a contents spill of a normal freight wagon.

- 0.1 * €5,678,665 = €567,866.

The costs of the measures themselves are unique to each measure, and we summarise the key cost components in Table 4.

## 6.2 Economic Indicators

Of course a measure will have an investment cost that is made today (or at the time that the measure is implemented) and returns benefits over a period of time. In these cases it is practice to consider this in the economic assessment. This is normally achieved by the use of the following economic indicators:

1. **Net Present Value** – the difference between the present value of cash inflows and the present value of cash outflows.
2. **Benefit / Cost Ratio** – the ratio of benefits to costs (a ratio greater than 1 indicates that the benefit outweighs the cost).
3. **Internal Rate of Return** - can be defined as the break-even interest rate which equates the Net Present of a projects cash flow in and out.

Our assumptions / clarifications regarding the use of these indicators are:

- We apply a discount rate of 4%.
- We assume that the measure is fully implemented at Year 1 and will return benefits in the same year.
- We have applied today's costs and benefits regardless of when the measure is implemented. We believe this to be a reasonable assumption as costs and benefits are likely to be stable within the periods defined as short and medium term.
- We have assumed that any investment is made by the EU Railway actors, for the benefit of EU Railway actors. This means that the economic analysis will focus entirely on costs and benefits within the EU without consideration that some benefits may in fact be transferred to stakeholders outside EU, or that there may be an inequitable share of costs and benefits between actors.

## Table 4 Cost and Benefits for Reference Case

| Measure | Purchase / Installation Costs | Annual Maintenance Cost | Max Potential Benefit[16] | Measure Effectiveness / Other Considerations | Net benefit[17] |
|---|---|---|---|---|---|
| **P-1: Check Rail** | €500 / metre[18].<br>**Total installation cost for 1,615 km = €807.5 million** | Additional maintenance cost of €5 / metre [2].<br>**Annual additional maintenance cost €8 million** | 25 avoided derailments | Assumed 90% effective where fitted [2] | **23 avoided derailments (6 HSD, 17 LSD)** |
| **P-2: Track Lubrication** | €3250 / installation[19].<br>**Total installation cost for 14,450 units = €47 million** | €3000 / installation (lubricant top-up)<br>**Annual additional maintenance cost €43 million** | 25 avoided derailments | Assumed 50% effective | **13 avoided derailments (10 LSD, 3 HSD)** |
| **P-10 & P-12: HABD/HWD** | €250k / installation<br>**Total installation cost for 3,530 €882.5 million** | Approx. 30 hours per year (supplier info)<br>**Annual additional maintenance cost €5.3 million** | 60 avoided derailments | 60 * 90% * 99% (99% being the availability figures for devices of this type, [2l]) | **53 avoided derailments (12 LSD, 41 HSD)** |
| **P-11: BAM** | €550k / installation<br>**Total installation cost for 578 units = €318 million** | 12 hours per year (supplier info)<br>**Annual additional maintenance cost €347,000** | 53 avoided derailments | 53 * 90% * 98% % (98% being the availability figures for devices of this type, [2l]) | **47 avoided derailments (11 LSD, 36 HSD)** |
| **P-13: Wheel Load / Impact Detectors** | €400k / installation<br>**Total installation cost for 450 units = €180 million** | 12 hours per year (supplier info)<br>**Annual additional maintenance cost €270,000** | 100 avoided derailments | 100 * 75% * 98% (98% being the availability figures for devices of this type, [2]) | **74 avoided derailments (33 LSD, 41 HSD)** |

[16] Refers to avoided derailments and related reduction of impacts
[17] Refers to avoided derailments and related reduction of impacts
[18] This is increased from the value used in our report [2]. Installation of check rails is likely to require change of sleepers or additional fixings for their attachment.
[19] This is a typical cost for a mechanical lubrication system installed and initially topped up with lubricant (supplier information)

| Measure | Purchase / Installation Costs | Annual Maintenance Cost | Max Potential Benefit[16] | Measure Effectiveness / Other Considerations | Net benefit[17] |
|---|---|---|---|---|---|
| **P-15: Bogie Hunting Detectors** | €385k / installation<br>**Total installation cost for 578 units = €222.5 million** | 15 hours per year (supplier info)<br>**Annual additional maintenance cost €433,500** | Max: 47 avoided derailments | 47 * 90% * 99% (99% being the availability figures for devices of this type, [2]) | **42 avoided derailments (30 LSD, 12 HSD)** |
| **P-16: Wheel Profile Monitoring** | €300k / installation<br>**Total installation cost for 548 units = €164 million** | 140 hours per year (supplier info). However, the regular pass-by check will be on opportunistic basis (100 hours). 40 hours of specific maintenance assumed.<br>**Annual additional maintenance cost €1 million** | Max: 23 avoided derailments | 23 * 90% * 95% (95% being the availability figures for devices of this type, [2]) | **20 avoided derailments (14 LSD, 6 HSD)** |
| **P-18 & P-21 Track Geometry** | **€170 million to upgrade 34,000 km side-track and secondary lines** | **Annual additional maintenance cost €85 million** | | | **58 avoided derailments (35 LSD, 23 HSD)** |
| **P-19: Clearance of Flange Groove** | **€6.7 million to perform 132,500 hours per year inspections (circa €50 / hour)** | **€6.7 million to perform 132,500 hours per year inspections (circa €50 / hour)** | 5 avoided derailments | 5 * 90% | **4.5 avoided derailments (0.5 LSD, 4 HSD)** |
| **P-28: Polyamide Roller Cages** | Assumed 1 hour per bearing at cost of €75 (including purchase)<br>**Total installation cost to replace 2 million brass roller cages = €150 million** | None | 44 avoided derailments | 44 * 75% | **33 avoided derailments (7 LSD, 26 HSD)** |
| **F-6: Anti-lock Devices** | €5,000 per wagon set<br>**Total installation cost for 720,000 units (all freight wagons) = €3600 million** | 30 mins / wagon per year<br>**Annual additional maintenance cost €18 million** | 27 avoided derailments | 27 * 75% | **20 avoided derailments (8 LSD, 12 HSD)** |

| Measure | Purchase / Installation Costs | Annual Maintenance Cost | Max Potential Benefit[16] | Measure Effectiveness / Other Considerations | Net benefit[17] |
|---|---|---|---|---|---|
| **F-7: Sliding Wheel Detectors** | €40,000 per installation<br>**Total installation cost for 1,320 units = €53 million** | Negligible, but has a life limited item that is replaced at 3 years ( €250 assumed)<br>**Three yearly additional maintenance cost €330,000** | 8 avoided derailments | 8 * 90% *99% (99% being the availability figures for devices of this type) | **7 avoided derailments (3 LSD, 4 HSD)** |
| **M1- Derailment Detection** | €2000 per wagon<br>**All Freight: Total installation cost for 718,000 wagons = €1436 million**<br>**All DG: Total installation cost for 98,000 wagons = €196 million**<br>**RID scope: Total installation cost for 15,500 wagons = €31 million** | Negligible, but has 6 year maintenance requirement (1 hour per wagon assumed)<br>**All freight (6 year) : €36 million**<br>**All DG (6 year) : €5 million**<br>**RID Scope (6 year) : €775,000** | N/A | 95% effective in detecting a derailment | **All freight: 76 derailments prevented from becoming severe**<br>**All DG: 10 derailments prevented from becoming severe**<br>**RID scope: 2 derailments prevented from becoming severe** |

# 7.0 Assessment Results – Reference Case

## 7.1 Quantitative Results Presentation

For the parameters established in this report, we show the results for our reference case.

### Table 5 Quantitative Analysis (Sorted by Measure Number)

| | Net Present Values | | | Benefit / Cost Ratio | | | Internal Rate of Return | | |
|---|---|---|---|---|---|---|---|---|---|
| Measure | 10 years | 20 years | 40 years | 10 Years | 20 Years | 40 Years | 10 years | 20 years | 40 years |
| P1-Check Rail | -701 | -635 | -559 | 0.2 | 0.3 | 0.4 | -31% | -14% | -6% |
| P2-Track Lubrication | -276 | -459 | -667 | 0.3 | 0.3 | 0.3 | N/A | N/A | N/A |
| P10&12-HABD/HWD | -507 | -257 | 27 | 0.5 | 0.7 | 1.0 | -16% | -4% | 0% |
| P11-BAM | 47 | 294 | 572 | 1.1 | 1.9 | 2.8 | 3% | 10% | 11% |
| P13-WLID/WIM | 379 | 756 | 1,183 | 3.1 | 5.1 | 7.4 | 51% | 52% | 52% |
| P15 Bogie Hunting Detector | 80 | 283 | 514 | 1.4 | 2.2 | 3.2 | 8% | 14% | 15% |
| P16-Wheel Profile | -27 | 65 | 170 | 0.8 | 1.4 | 1.9 | -4% | 5% | 7% |
| P18-Track Geometry | -373 | -568 | -788 | 0.5 | 0.6 | 0.6 | N/A | N/A | N/A |
| P19-Clearance Flange Groove | -20 | -34 | -49 | 0.6 | 0.6 | 0.6 | N/A | N/A | N/A |
| P28-Roller Cages | 109 | 284 | 482 | 1.7 | 2.9 | 4.2 | 16% | 21% | 21% |
| F6-Anti Lock Device | -3,581 | -3,581 | -3,580 | 0.0 | 0.1 | 0.1 | N/A | N/A | N/A |
| F7-Sliding Wheel Detector | -0 | 35 | 75 | 1.0 | 1.6 | 2.4 | 0% | 7% | 9% |
| M1a-Derail Det All Freight | -385 | 303 | 1,094 | 0.7 | 1.2 | 1.7 | -7% | 3% | 5% |
| M1a-Derail Det All DG | -44 | 56 | 170 | 0.8 | 1.3 | 1.8 | -6% | 3% | 6% |
| M1a-Derail Det RID | -2 | 17 | 39 | 0.9 | 1.5 | 2.2 | -2% | 6% | 8% |

### Table 6 Quantitative Analysis (Sorted by Benefit / Cost ratio)[20]

| | | Net Present Values | | | Benefit / Cost Ratio | | | Internal Rate of Return | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Rank | Measure | 10 years | 20 years | 40 years | 10 Years | 20 Years | 40 Years | 10 years | 20 years | 40 years |
| 1 | P13-WLID/WIM | 379 | 756 | 1,183 | 3.1 | **5.1** | 7.4 | 51% | 52% | 52% |
| 2 | P28-Roller Cages | 109 | 284 | 482 | 1.7 | **2.9** | 4.2 | 16% | 21% | 21% |
| 3 | P15 Bogie Hunting Detector | 80 | 283 | 514 | 1.4 | **2.2** | 3.2 | 8% | 14% | 15% |
| 4 | P11-BAM | 47 | 294 | 572 | 1.1 | **1.9** | 2.8 | 3% | 10% | 11% |
| 5 | F7-Sliding Wheel Detector | -0 | 35 | 75 | 1.0 | **1.6** | 2.4 | 0% | 7% | 9% |
| 6 | M1a-Derail Det RID | -2 | 17 | 39 | 0.9 | **1.5** | 2.2 | -2% | 6% | 8% |
| 7 | P16-Wheel Profile | -27 | 65 | 170 | 0.8 | **1.4** | 1.9 | -4% | 5% | 7% |
| 8 | M1a-Derail Det All DG | -44 | 56 | 170 | 0.8 | **1.3** | 1.8 | -6% | 3% | 6% |
| 9 | M1a-Derail Det All Freight | -385 | 303 | 1,094 | 0.7 | **1.2** | 1.7 | -7% | 3% | 5% |
| 10 | P10&12-HABD/HWD | -507 | -257 | 27 | 0.5 | **0.7** | 1.0 | -16% | -4% | 0% |
| 11 | P19-Clearance Flange Groove | -20 | -34 | -49 | 0.6 | **0.6** | 0.6 | N/A | N/A | N/A |
| 12 | P18-Track Geometry | -373 | -568 | -788 | 0.5 | **0.6** | 0.6 | N/A | N/A | N/A |
| 13 | P1-Check Rail | -701 | -635 | -559 | 0.2 | **0.3** | 0.4 | -31% | -14% | -6% |
| 14 | P2-Track Lubrication | -276 | -459 | -667 | 0.3 | **0.3** | 0.3 | N/A | N/A | N/A |
| 15 | F6-Anti Lock Device | -3,581 | -3,581 | -3,580 | 0.0 | **0.1** | 0.1 | N/A | N/A | N/A |

The top nine measures (Wheel Load Impact Detectors to Wheel Profile Detectors) show a positive NPV and therefore greater than unity benefit to cost ratio at Year 20, whilst the tenth best measure, Hot Axle Box / Hot Wheel Detectors is unable to show overall benefit at this point.

[20] Note that IRR cannot compute measures where, for example, the cost exceeds the benefit beyond Year 1. We therefore rank our measures based on B/C ratio. We also use the results at year 20, as these are the likely lifecycles for each measure considered.

## 7.2 Qualitative Results Presentation

An alternative non-financial presentation is provided below.

**Table 7 Qualitative Analysis (Sorted by Measure Number)**

| Measure | Fats | Track (km) | Wagons (number) | Opeartions (hrs) | Environmental events | Derails prevented |
|---|---|---|---|---|---|---|
| P1-Check Rail | 0.16 | 35 | 109 | 751 | 3 | 23 |
| P2-Track Lubrication | 0.09 | 20 | 61 | 422 | 2 | 13 |
| P10&12-HABD/HWD | 0.47 | 70 | 270 | 1889 | 8 | 53 |
| P11-BAM | 0.41 | 63 | 240 | 1673 | 7 | 47 |
| P13-WLID/WIM | 0.59 | 104 | 366 | 2542 | 10 | 74 |
| P15-Bogie Hunting Detector | 0.29 | 63 | 199 | 1377 | 5 | 42 |
| P16-Wheel Profile | 0.14 | 30 | 95 | 657 | 2 | 20 |
| P18-Track Geometry | 0.36 | 85 | 280 | 1941 | 7 | 58 |
| P19-Clearance Flange Groove | 0.04 | 6 | 23 | 164 | 1 | 4.5 |
| P28-Roller Cages | 0.29 | 44 | 169 | 1180 | 6 | 33 |
| F6-Anti Lock Device | 0.17 | 28 | 99 | 693 | 3 | 20 |
| F7-Sliding Wheel Detector | 0.06 | 10 | 35 | 241 | 1 | 7 |
| | | | | | | Severe derailments saved |
| M1a-Derail Det All Freight | 0.96 | 341 | 379 | 2881 | 17 | 76 |
| M1a-Derail Det All DG | 0.85 | 45 | 50 | 380 | 4 | 10 |
| M1a-Derail Det RID | 0.12 | 9 | 10 | 76 | 1 | 2 |

In this table it is of course not surprising to see that the measures with the best economic performance secure the largest benefit.

It is interesting to note however that “M” measures show the largest absolute benefit. This is because they are intended to prevent the escalation of consequences, and therefore target only the most serious outcomes.

To illustrate this point we consider measure M1 applied to all DG trains (M1a-Derail All Freight and P13- WLID/WIM detectors. We can see that M1a-Derail Det All Freight prevents 76 derailments from becoming severe whilst P13 prevents 74 derailments from occurring at all. On first consideration it may seem that preventing 74 derailments is the better outcome. However, of these 74, a number will be safely managed and not escalate in consequence, therefore only a proportion of these prevented derailments are severe. Further, since it is only severe derailments that lead to loss of life, preventing severe derailments has significant advantages in this respect.

## 7.3 Additional Measures and Discussion Points

### 7.3.1 Measure P28-(Polyamide) Roller Cages

An alternative opportunity exists for this measure, as introduced earlier in our report. That is the replacement of brass for polyamide roller cages at the next appropriate maintenance interval. We are not able to assess this in an economic sense as it has almost no cost.

The benefit will accrue over time, as a function of the maintenance intervals for wagons.

### 7.3.2 Measure M1-Derailment Detection

We have assessed only those measures that invoke an emergency braking (M-1a), not those that provide an alarm to the train driver (M-1b). The latter would require the train driver to take appropriate action although it is difficult to envisage an appropriate action that does not involve bringing the train to the prompt stop.

We have not identified any measures of type M-1b on the market, although we have to conclude that these would be more expensive that the “simple” M-1a measures. Additional technology would be required, possibly involving the provision of power, transmitting and receiving technology or some other form of alarm transfer. There is also likely to be a substantial training requirement to instruct the train driver how to react in an alarm situation.

Considering M-1b measures we therefore cannot conclude that these measures bring the same benefit as M-1a measures as new failure modes are introduced, including human error.

# 8.0 Sensitivity Analysis

## 8.1 Motivation

It is necessary for a study of this complexity to make certain assumptions regarding modelling parameters; this work is no different in that respect.

Whilst we have endeavoured to research and validate our assumptions, it is prudent to test the key assumptions to determine if the results are robust when subject to reasonable variance.

This is the purpose of our sensitivity analysis.

## 8.2 Method and Results

We considered two cases:

1. A minimising set of parameters; these present what we consider to the reasonable "worst case" in minimising the interests of each measure. These concentrate on:
    a. The assessed reasonable minimum effectiveness of the measure (leading to a reduced number of derailments avoided / detected and hence reduced benefit).
    b. The assessed reasonable increased application scope for the measure (leading to an increased quantity of that measure and hence an increased cost).
2. A maximising set of parameters; these present what we consider to the reasonable "best case" in maximising the interests of each measure.
    a. The assessed reasonable maximum effectiveness of the measure (leading to an increased number of derailments avoided / detected and hence increased benefit).
    b. The assessed reasonable reduced application scope for the measure (leading to a reduced quantity of that measure and hence a reduced cost).

We have limited our attention to application scope and effectiveness. Our set of minimising and maximising parameters is presented at Appendix I of this report and the results below.

**Table 8 Quantitative Analysis (Sorted by Benefit / Cost ratio) – Minimising Parameters**

| | | Net Present Values | | | Benefit / Cost Ratio | | | Internal Rate of Return | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Rank | Measure | 10 years | 20 years | 40 years | 10 Years | 20 Years | 40 Years | 10 years | 20 years | 40 years |
| 1 | P13-WLID/WIM | 171 | 511 | 896 | 1.5 | **2.5** | 3.6 | 12% | 17% | 17% |
| 2 | P28-Roller Cages | -60 | 56 | 188 | 0.7 | **1.2** | 1.8 | -7% | 3% | 5% |
| 3 | P15 Bogie Hunting Detector | -121 | 47 | 237 | 0.7 | **1.1** | 1.6 | -8% | 2% | 4% |
| 4 | P11-BAM | -188 | 42 | 301 | 0.6 | **1.1** | 1.6 | -9% | 1% | 4% |
| 5 | M1a-Derail Det All Freight | -601 | -59 | 567 | 0.6 | **1.0** | 1.4 | -11% | -1% | 3% |
| 6 | M1a-Derail Det RID | -16 | -6 | 5 | 0.5 | **0.8** | 1.1 | -14% | -3% | 1% |
| 7 | M1a-Derail Det All DG | -103 | -42 | 27 | 0.5 | **0.8** | 1.1 | -14% | -3% | 1% |
| 8 | F7-Sliding Wheel Detector | -42 | -17 | 11 | 0.5 | **0.8** | 1.1 | -15% | -3% | 1% |
| 9 | P10&12-HABD/HWD | -530 | -295 | -30 | 0.4 | **0.7** | 1.0 | -17% | -4% | 0% |
| 10 | P16-Wheel Profile | -170 | -97 | -15 | 0.4 | **0.7** | 1.0 | -17% | -5% | 0% |
| 11 | P18-Track Geometry | -453 | -697 | -972 | 0.5 | **0.5** | 0.5 | N/A | N/A | N/A |
| 12 | P1-Check Rail | -1,597 | -1,597 | -1,595 | 0.1 | **0.1** | 0.2 | N/A | N/A | N/A |
| 13 | P2-Track Lubrication | -446 | -743 | -1,080 | 0.1 | **0.1** | 0.1 | N/A | N/A | N/A |
| | P19-Clearance Flange Groove | Not modelled | | | | | | | | |
| | F6-Anti Lock Device | Not modelled | | | | | | | | |

**Table 9 Quantitative Analysis (Sorted by Benefit / Cost ratio) – Maximising Parameters**

| | | Net Present Values | | | Benefit / Cost Ratio | | | Internal Rate of Return | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Rank | Measure | 10 years | 20 years | 40 years | 10 Years | 20 Years | 40 Years | 10 years | 20 years | 40 years |
| 1 | P13-WLID/WIM | 409 | 806 | 1,257 | 3.2 | **5.4** | 7.8 | 56% | 57% | 57% |
| 2 | P28-Roller Cages | 190 | 386 | 608 | 2.9 | **4.9** | 7.1 | 45% | 47% | 47% |
| 3 | P15-Bogie Hunting Detector | 93 | 307 | 548 | 1.4 | **2.3** | 3.4 | 10% | 15% | 16% |
| 4 | M1a-Derail Det RID | 12.45 | 41.34 | 74.30 | 1.39 | **2.3** | 3.23 | 0.09 | 0.15 | 0.15 |
| 5 | P11-BAM | 78 | 346 | 649 | 1.2 | **2.1** | 3.0 | 6% | 12% | 13% |
| 6 | F7-Sliding Wheel Detector | 7 | 47 | 92 | 1.1 | **1.9** | 2.7 | 3% | 10% | 11% |
| 7 | M1a-Derail Det All DG | -15 | 105 | 242 | 1 | **1.5** | 2 | -0 | 0 | 0 |
| 8 | P16-Wheel Profile | -19 | 79 | 189 | 0.9 | **1.4** | 2.0 | -3% | 5% | 7% |
| 9 | M1a-Derail Det All Freight | -212 | 593 | 1,516 | 0.9 | **1.4** | 2.0 | -4% | 5% | 7% |
| 10 | P10&12-HABD/HWD | -484 | -218 | 83 | 0.5 | **0.8** | 1.1 | -15% | -3% | 1% |
| 11 | P18-Track Geometry | -293 | -439 | -605 | 0.6 | **0.6** | 0.6 | N/A | N/A | N/A |
| 12 | P1-Check Rail | -267 | -178 | -76 | 0.4 | **0.6** | 0.8 | -20% | -6% | -1% |
| 13 | P2-Track Lubrication | -110 | -182 | -264 | 0.6 | **0.6** | 0.6 | N/A | N/A | N/A |
| 14 | P19-Clearance Flange Groove | Not modelled | | | | | | | | |
| 15 | F6-Anti Lock Device | Not modelled | | | | | | | | |

We have not modelled F6-Anti lock device as it considered clear from our reference case that it cannot be cost-effective. Further, we have eliminated P19-Clerance of Flange Groove as we believe our reference case already shows this measure in its best possible light and it still remains outside the top ten when compared with other measures (and this is a measure that we do not consider the Agency would be minded to make a specific recommendation on as it should be part of each IM's SMS).

We note here that although there is some re-ordering of priority our list of top ten measures remains unchanged.

## 8.3 Summary and Results Discussion

We were surprised to note measure F-7 appearing towards the top of the ranking (reference and sensitivity), however we do acknowledge that in our consultation exercise at least one IM did state this to be a known problem. Although the quantity of avoided derailments is relatively low, the cost of the measure is also relatively low, with low maintenance and upkeep costs.

Also measure P-28 has been assessed on the basis of fitting polyamide roller cages with immediate effect. We have also discussed an alternative option which is for the replacement of brass for polyamide roller cages at the next scheduled maintenance interval for axles / axle boxes. This is almost a zero cost option, although the benefits would take longer to materialise, and be a function of the maintenance cycle for freight wagons.

Measure P-11 would involve a radical departure from the existing means of addressing hot axle box derailments, which are controlled in the EU through other means. If these other means can be successful in reducing this as a derailment cause then the benefit of BAM will diminish also.

# 9.0 Qualitative Assessment

## 9.1 Technical Measures

### 9.1.1 Measure P-9: Interlocking Of Points Operation While Track Occupied

Our analysis [3] of accidents associated with points movement under a train indicates a small number of derailments from this cause mostly resulting from a lack of train detection / interlocking protection. These accidents usually occur at station entrances and exits. We estimated [3] 11 per annum, mostly low speed. (We have not considered shunting operations derailments, of which there are many.) Due to the relatively low number of derailments, and the relatively low consequence of such derailments, we have not researched data for a quantitative analysis.

Whilst this is the case, some locations could be addressed by a relatively low cost "fix". In particular, if the point is electrically operated centrally from a signal box then the cost to implement a solution could be relatively small (we estimated a cost of €10,000 [2] for an additional track circuit (plus installation costs)). Also, we are able to assume that interlocking protection is very effective, as this is a high integrity system (although the possibility for human error exists).

We feel that is unlikely that the Agency would consider a specific recommendation for this measure on the basis of its low risk and also that such interlocking is not fitted in higher risk locations. Whilst we therefore do not offer this as a recommendation, it may prove cost-effective in mitigating a number of lower consequence freight (and passenger) train derailments and could form the basis of an advisory notice.

### 9.1.2 P-20: Ultrasonic Rail Inspection

Our analysis [3] of accidents associated with rail failures indicated up to 18 derailments per year annually potentially resulting from this cause. We also recognise that ultrasonic rail inspection is an effective technique to combat this problem.

However, whilst this is the case we note that this measure is extensively applied already. We therefore conclude that it is not the technical measure that requires strengthening; rather it is the frequency of its usage and also the analysis and implementation of findings that should be addressed which we consider an organisational issue.

### 9.1.3 Measure P-34: Secure Brake Gear Underframe

Our analysis [3] of accidents associated with braking components becoming loose and falling from a train indicated a small number of derailments potentially resulting from this cause (approximately 7 freight train derailments annually).

We consider that the cost of applying this measure to all freight wagons currently not equipped with a safety sling or appropriate containment system is likely to prove expensive as it will require an engineered solution bespoke to the wagon type. It is also possible that the measure may introduce its own risks, with the possibility that the safety sling itself becomes a derailment risk if not properly maintained.

We therefore have concluded that this measure would not be suitable for recommendation by the Agency.

## 9.2 Operational Measures

### 9.2.1 P-40: Qualified and Registered Person Responsible for Loading

Loading errors can contribute significantly to freight train derailments, usually in combination with other defects such as poor train handling or adverse track geometry. Control of such events is covered by national and local rules, which in some cases include the use of externally qualified loading personnel.

To strengthen this control through the EU, it could be considered to require the qualification and registration of loading personnel. However, although the problem of train loading is an issue of importance, we question how effective a measure like this may be. In particular:

- Freight train loading rules and controls are already in place, and allocated to persons through each RU's safety management system. An external qualification is unlikely, in our opinion, to have a significant impact in reducing the incidence of such events.
- The costs associated with designing and maintaining a qualification system is likely to be expensive as well as time consuming to implement.

We consider that better enforcement of existing controls is likely to be a more fruitful approach and therefore do not consider this measure further.

### 9.2.2 P-41: Locomotive and First Wagons of Long Freight Trains in Brake Position G; P-42: Limitations of Brake Action

We identified these as examples of existing measures that are currently applied in many countries, where required. There are potential drawbacks also with these measures in that they may reduce the braking effort available to the operator and therefore may contribute to derailments and other accidents or incidents.

On the basis that measures of this type are based on local operating conditions, it would not be appropriate or possible to propose an EU wide rule covering the intent. It is therefore a matter for national and company attention and we do not consider this further.

### 9.2.3 P-43: Dynamic Brake Test On-route

Some countries, such as Sweden, Finland and Norway support this functionality. However, we consider [3] that the potential in terms of derailment avoidance is relatively small and is unlikely to support making this a special provision.

It would be considered that a decision on this topic is best placed at the National level. We do not consider this further.

### 9.2.4 P-46 Not Allowing Traffic Controllers and Drivers to Override Detector Alarms

We have reported [3] a number of accidents that have occurred despite a warning being provided to the traffic controller and the incident train being allowed to continue. In this regard we consider that the use of the use of more modern integrated monitoring detection stations will go some way to eliminating this problem.

This is also conditioned by local operating constraints such as the location of detection stations and the availability of inspection locations.

All national "rule books" and operating instructions deal with operating in degraded conditions, and this we believe should continue to the case for alarm management.

### 9.2.5 P-47: Wagons Equipped with a Balance to Detect Overload in Visual Inspection

This is an interesting measure that has a role on a voluntary basis. It may provide partial protection against loading errors, in particular skew loading. Such a measure may be useful when a load is containerised and cannot easily be inspected.

Whilst we cannot consider that an EU regulation may be developed for this specific measure, it may be put forward as an advisory note for the voluntary consideration of wagon owners.

## 9.3 Organisational Measures

### 9.3.1 P22 to P-25: EU Intervention Limits

We have considered the issue of general maintenance for side-tracks at measures P-18 and P-21. As a separate issue we address the issue of intervention limits. This would apply to the main-line network.

It is clear that derailments, particularly those which are attributable to track twist, are a major concern. We estimated between 34 and 50 per annum; these include cases where track twist (for example) are within existing safety limits, but due to unfortunate freight train composition and loading (which may also be within relevant criteria) combine to cause a derailment. It may be the case that future possible changes in freight traffic, more containerisation and increased use of single axle wagons may require these parameters to be addressed just to maintain the status-quo. Further, for an interoperable and open railway, track parameters should be as consistent as possible so that freight train can pass safely through each country. A system of common and stricter safety limits and intervention limits would be a step forward.

Whilst we have estimated the potential benefit we cannot estimate the effort and expense that would be required to bring the EU railway up to a similar standard. We therefore are unable to perform a quantified analysis for this group of measures.

We also note that there would be some significant hurdles to cross regarding what a revised set of safety and intervention limits might be, the capture of these in a revised Infrastructure TSI for and then the implementation of these through the EU railway system.

We have therefore not considered this group of measures beyond this discussion.

### 9.3.2 F-2: Awareness Programme for Rolling Stock Maintenance

During our consultation exercise it was reported by IMs that some rolling stock operating on their networks was of a poor standard / poorly maintained. Also, we have identified a number of specific measures related to this issue, these being:

- P-35: Regular greasing and checks of rolling stock buffers.
- P-36: Wheel-set integrity inspection.
- P-39: Double check and signing of safety-classified maintenance operations.

If we can include hot axle box derailments and axle failures in the category of rolling stock maintenance related problems, then the benefit in terms of avoided derailments is very significant indeed. We are however unable to estimate the expense that may be required, in terms of increased maintenance, that would make significant in-roads into this problem.

On the basis of their being more than 100+ freight train derailments associated with wheel-set and axle failures, and with an average cost that may approach €1,000,000 per derailment [3] would suggest a substantial investment could be justified.

We may consider two options:

1. Initially the development of an awareness training programme, that sought to concentrate on main rolling stock maintenance derailment causes, and best practice (which could include measures P-38 in addition to those listed above). This could possibly be developed through the Agency, and rolled out to RUs and Entities in Charge of Maintenance (ECMs).
2. A second set of measures directed towards NSAs and concerned with Supervision of this aspect.

# 10.0 Other Issues

## 10.1 Identified Drawbacks

We have not so far considered potential drawbacks associated with our quantified and qualitative assessments of measures.

### 10.1.1 Provoking Derailments

We consider that measures P1-Check Rail and M1-Derailment Detection (types that apply full emergency train braking) have a common drawback. That is that they each may provoke derailments (albeit not very frequently).

For example an accident in Finland on 09 March 2009 had as a cause "***ice packed in the flange way between the crossing frog and the check rail in a turnout***". Poor alignment and maintenance of check rails may also contribute to derailments.

Similarly, train compression under heavy braking is also a known cause of derailments and hence a false alarm of some M1 devices may lead to this outcome. In this respect we note that CSM Regulation, Annex I, point 2.5.4 states:

*For technical systems where a functional failure has credible direct potential for a catastrophic consequence, the associated risk does not have to be reduced further if the rate of that failure is less than or equal to $10^{-9}$ per operating hour.*

It is possible that these measures may require to be demonstrated to meet this stipulation prior to any further recommendation being made.

### 10.1.2 False Alarms

False alarms are a potential issue with the majority of technical measures discussed in this report although some may have more direct impacts than others.

Measures based on trending or to detect early defects are less likely to have a service affecting consequence. We consider technical measures ***P11-BAM; P13-WLID; P15-Bogie Hunting; P16-Wheel Profile*** fall into this category. Alarms or warnings are likely to be dealt with at a convenient time without undue impact on the operational railway.

Measure ***P10/12-HABD/HWD and F7-Sliding Wheel Detectors*** are, in our opinion, more likely to have operational impacts as they may need more immediate attention which could involve bringing the incident train to an immediate stop (although in the case of the latter this is likely to be in at a location where an inspection is relatively straightforward and not service affecting).

### 10.1.3 Market Competition / Advantage

Measure F-7-Sliding Wheel Detectors are as far as we are able to establish a technology (in the form that we have considered) that is provided by a small number of suppliers.

## 10.2 Potential Combinations

A number of measures address the same issues (which is not surprising since there are a relatively small number of high likelihood derailment causes).

Detection of hot axle box conditions is covered by ***P10/12-HABD/HWD; P11-BAM; P13-WLID*** (indirectly through the detection of leading indicators). Measure ***P28-Roller Cages*** also addresses the same problem.

The measures are not mutually exclusive however, and could be applied in combination. For example ***P11-BAM*** could be applied to long distance freight routes to provide optimum

coverage at minimum cost (compared to other measures that require a much denser population of detection sites). This could be supplemented by the use of measure ***P10/12-HABD/HWD*** for shorter freight routes and strategic points of the network at critical locations.

Further, to the best of our knowledge, measure ***P28-(Polyamide) Roller Cages*** does not impinge on the effectiveness of existing detection systems, although this may need to be tested to confirm this manufacturer's claim. Further, it could be postulated that polyamide roller cages offer improved performance under emergency running and may allow an extension of the distance between detection sites thus allowing a lower density level for measure ***P10/12-HABD/HWD.***

# 11.0 Conclusions and Recommendations

## 11.1 Important Remarks

It is important to clarify that this report looks at the ***potential for improvement***, and is not an absolute assessment of the efficiency of all measures that are applied today. Therefore it follows that if a measure is applied extensively already there is little room for improvement through the further application of that measure. For this reason some measures that are extensively applied already are not considered in this work. Their omission should not be considered as suggesting such measures are not efficient.

In this context the measures listed in this section can be seen as efficient in addressing the potential reduction in risks associated with freight train derailments and providing the detailed background against which public policy can be formulated.

The assessment of measures does not consider the way or the order in which these interventions should be pursued, for example it is not considered whether these interventions should be introduced in a mandatory or voluntary way or whether the measure should be introduced as an EU harmonised measure or only within certain member states or only certain companies.

## 11.2 Efficiency Assessment of Measures

### 11.2.1 Technical Preventative Measures

We consider the following technical measures as being efficient (they have a positive or unity benefit / cost ratio in our reference case and all sensitivity studies):

- P13-Wheel Load Impact Detectors / Weighing In Motion
- P28-Replacement of Brass for Polyamide Roller Cages
- P15-Bogie Hunting Detectors
- P11-Bearing Acoustic Monitoring

Considering measure P28, we have considered an immediate replacement of brass for polyamide roller cages. We have also discussed an alternative option which is for the replacement of brass for polyamide roller cages at the next scheduled maintenance interval for axles / axle boxes. This is almost a zero cost option, although the benefits would take longer to materialise, and be a function of the maintenance cycle for freight wagons.

Potential drawbacks to the use of these measures (excluding measure P28) relate to the rate of false alarms. To some extent these can be overcome by the use of good alarm management processes. Further false alarms from those technical measures that are based on early defect detection are unlikely to have an immediate operational impact.

In addition the following two measures are efficient based on the parameters in our reference case:

- F7-Sliding Wheel Detectors
- P16-Wheel Profile Detectors

Potential drawbacks include false alarms as reported above. Finally, measure F7 is to the best of our knowledge a market with only a small number of suppliers. This may give rise to market advantage to existing suppliers of these systems if they were to form the basis of formal recommendation.

### 11.2.2 Technical Mitigation Measures

We consider the following mitigation measure as potentially efficient if the significant identified drawbacks could be solved:

- M1a-Derailment Detection (with automatic brake application) applied to All Freight Trains

This present assessment is fully in line with the previous assessment made by the Agency [7]. The significant drawback previously identified is confirmed by the present study and the related accident analysis. A false alarm of such a device may lead to train compression which is a contributory cause of freight train derailments (and also a significant operational disruption). In this respect we note that CSM Regulation, Annex I, point 2.5.4 states:

*For technical systems where a functional failure has credible direct potential for a catastrophic consequence, the associated risk does not have to be reduced further if the rate of that failure is less than or equal to $10^{-9}$ per operating hour.*

(Measure P1: Check rail has similar disadvantages, although this is not considered efficient by our assessment.)

Finally, we acknowledge an alternative type of derailment detection device which provides an alarm to the train driver when a derailment is suspected, but without an automatic brake application (type M1b). We are however not aware of these being available on the market (for freight application). We consider that an assessment of these devices, considering the human factors issues involved and their costs would be required before these could be formally assessed.

### 11.2.3 Organisational Measures

We note that the measures above are technical measures that are aimed at addressing, in some cases, organisational problems. Therefore we would add the following organisational and supervision items:

- F-2: Awareness Programme for Rolling Stock Maintenance. This measure may serve to address the problem of poor maintenance standards of rolling stock. This may include training that sought to concentrate on main rolling stock maintenance derailment causes (which can be extracted from our task report, [3]) and best practice. This measure may be followed by increased supervision of these parameters by NSAs to ensure that practicable risk reduction objectives are being applied.
- P-18: Track Geometry (all tracks). Although the case for improvements in this area are not conclusively made from a quantified perspective, the problem of poor track geometry (in particular track twist), and the possible requirement to improve this aspect just to maintain current performance levels (see Section 9.3.1) should be considered. This is of course an area for each IMs own management system. However a specific measure in this regard must be concerned with increased supervision of these parameters by NSAs to ensure that practicable risk reduction objectives are being applied.

The two measures above represent significant contributors to the derailment problem and organisational failures of individual IMs and RUs in fulfilling their obligations.

## 12.0 References

1. Assessment of existing technical and operational measures against freight train derailments in the Community's railways, Contract ERA/2010/SAF/OP/01.
2. Assessment of freight train derailment risk reduction measures: Part A Final Report for European Railway Agency, DNV report No: BA000777/01 July 2011.
3. Assessment of freight train derailment risk reduction measures: Part B2 – Risk model and potential effectiveness of measures for European Railway Agency, DNV report No: BA000777/07 July 2011.
4. European Railway Technology Review. Wayside Train Monitoring Systems, ISBN 978-3-7771-0426-3 dated 2011
5. Compact Tapered Roller Bearings, SKF Publication 6328/EN, dated 2008, www.railways.skf.com
6. New ZKL Bearings for Railway Axleboxes, ZKL Bearings, http://en.lily-bearing.com/bearing_news/08062003.htm
7. Impact Assessment on the use of Derailment Detector Devices in the EU Railway System, ERA/REP/03-2009/SAF dated May 2009
8. Rail Infrastructure Cost Benchmarking, BSL Final Report, April 2008.
9. Assessment of freight train derailment risk reduction measures: Part A3 – Functional and Performance Assessment for European Railway Agency, DNV report No: BA000777/04 April 2011.

# 13.0 Appendix I: Sensitivity Parameters

## Table 10 Sensitivity Parameters (Minimising Parameters)

| Measure | Max Potential Benefit (Ref) | Net benefit (Ref) | Sensitivity (Eff.min) | Sensitivity (App.min) | Justification / Comment |
|---|---|---|---|---|---|
| **P-1: Check Rail** | 25 avoided derailments | 23 avoided derailments | Measure effectiveness reduced to 75%. New net benefit = 19 avoided derailments. | Application scope doubled. (Hence 3,230 km.) | Existing measure well proven. Effectiveness considered to be quite tightly constrained around reference value. Small negative variation applied.<br>Application scope estimated, and could have high variance. |
| **P-2: Track Lubrication** | 25 avoided derailments | 13 avoided derailments | Measure effectiveness reduced to 25%. New net benefit = 6 avoided derailments. | Two lubrication units per side track required. (Hence 19,266 units.) | Derailment prevention is a secondary benefit of this measure. Effectiveness as a derailment prevention measure difficult to establish, which is reflected in the selection of sensitivity parameters. |
| **P-10 & P-12: HABD/HWD** | 60 avoided derailments | 53 avoided derailments | Measure effectiveness reduced to 85%. New net benefit = 50 avoided derailments. | No change | Existing measure well proven. Effectiveness considered to very tightly constrained around reference value. Small negative variation applied<br>Application scope – no significant variation likely |
| **P-11: BAM** | 53 avoided derailments | 47 avoided derailments | Measure effectiveness reduced to 85%. New net benefit = 44 avoided derailments. | One unit per 300 km, hence 960 units. | Existing measure well proven. Effectiveness considered to very tightly constrained around reference value. Small negative variation applied<br>Application scope - shorter routes in Europe compared with existing installed base may require more units. |
| **P-13: Wheel Load / Impact Detectors** | 100 avoided derailments | 74 avoided derailments | Measure effectiveness reduced to 70%. New net benefit = 67 avoided derailments. | One unit per 300 km, hence additional 832 units. | Existing measure well proven. Effectiveness considered to very tightly constrained around reference value. Small negative variation applied<br>Application scope – to adequately cover short-haul routes more units may be required (assumed as BAM) |
| **P-15: Bogie Hunting Detectors** | Max: 47 avoided derailments | 42 avoided derailments | Measure effectiveness reduced to 75%. New net benefit = 35 avoided derailments. | One unit per 300 km, hence 960 units. | Not significantly installed in Europe. Sensitivity value selected to reflect unproven in Europe.<br>Application scope - shorter routes in Europe compared with existing installed base may require more units. |

| Measure | Max Potential Benefit (Ref) | Net benefit (Ref) | Sensitivity (Eff.min) | Sensitivity (App.min) | Justification / Comment |
|---|---|---|---|---|---|
| **P-16: Wheel Profile Monitoring** | Max: 23 avoided derailments | 20 avoided derailments | Measure effectiveness reduced to 80%. New net benefit = 17 avoided derailments. | One unit per 300 km, hence 934 additional units. | Existing measure well proven. Effectiveness considered to very tightly constrained around reference value. Small negative variation applied<br>Application scope – to adequately cover short-haul routes more units may be required (assumed as BAM) |
| **P-18 & P-21 Track Geometry** | Max: 129 avoided derailments | 58 avoided derailments | No change | 10% cost increase in year 1, and subsequent years. Hence €187 mill and €93 mill respectively. | Effectiveness no change from reference value.<br>Application scope – amount of track requiring additional attention estimated. |
| **P-19: Clearance of Flange Groove** | Not modelled. We consider that we have already applied optimistic parameters and shown this measure to be able to be discarded without further consideration. | | | | |
| **P-28: Polyamide Roller Cages** | 44 avoided derailments | 33 avoided derailments | Measure effectiveness reduced to 50%. New net benefit = 22 avoided derailments. | 50% increase in brass roller cages (3 million) | Effectiveness unproven scientifically, reflected in reduction in this parameter.<br>Application – increase in quantity of brass roller cages |
| **F-6: Anti-lock Devices** | Not modelled. No further negative assumptions applicable. | | | | |
| **F-7: Sliding Wheel Detectors** | 8 avoided derailments | 7 avoided derailments | Measure effectiveness reduced to 75%. New net benefit = 5 avoided derailments. | 50% increase in density, hence 1980 units. | Existing measure well proven (although not in Europe). Sensitivity value selected to reflect unproven in Europe.<br>Application scope – we consider there to be some uncertainty around the density required to achieve the assigned benefit. A 50% increase in density is modelled for this measure |
| **M1-Derailment Detection** | N/A | N/A | Measure effectiveness reduced to 90%. | No change | We believe the measure is effective with little variance. Small negative variation applied.<br>Application scope – unchanged. |

## Table 11 Sensitivity Parameters (Maximising Parameters)

| Measure | Max Potential Benefit (Ref) | Net benefit (Ref) | Sensitivity (Eff.min) | Sensitivity (App.min) | Justification / Comment |
|---|---|---|---|---|---|
| **P-1: Check Rail** | 25 avoided derailments | 23 avoided derailments | No change | Application scope halved to 800 km. | Effectiveness not considered to significantly exceed reference value.<br>Application scope estimated, and could have high variance. |
| **P-2: Track Lubrication** | 25 avoided derailments | 13 avoided derailments | Measure effectiveness increased to 75%. New net benefit = 19 avoided derailments. | One lubrication units per side track required. (Hence 9,633 units.) | Derailment prevention is a secondary benefit of this measure. Effectiveness as a derailment prevention measure difficult to establish, which is reflected in the selection of sensitivity parameters. Small positive variation applied. |
| **P-10 & P-12: HABD/HWD** | 60 avoided derailments | 53 avoided derailments | Measure effectiveness increased to 95%. New net benefit = 56 avoided derailments. | No change | Existing measure well proven. Effectiveness considered to very tightly constrained around reference value. Small positive variation applied.<br>Application scope – no significant variation likely |
| **P-11: BAM** | 53 avoided derailments | 47 avoided derailments | Measure effectiveness increased to 95%. New net benefit = 50 avoided derailments. | No change | Existing measure well proven. Effectiveness considered to very tightly constrained around reference value. Small positive variation applied<br>Application scope – no significant variation likely |
| **P-13: Wheel Load / Impact Detectors** | 100 avoided derailments | 74 avoided derailments | Measure effectiveness increased to 80%. New net benefit = 78 avoided derailments. | No change | Existing measure well proven. Effectiveness considered to very tightly constrained around reference value. Small positive variation applied<br>Application scope – no significant variation likely |
| **P-15: Bogie Hunting Detectors** | Max: 47 avoided derailments | 42 avoided derailments | Measure effectiveness increased to 95%. New net benefit = 44 avoided derailments. | No change | Effectiveness: Small positive variation applied<br>Application scope – no significant variation likely |
| **P-16: Wheel Profile Monitoring** | Max: 23 avoided derailments | 20 avoided derailments | Measure effectiveness increased to 95%. New net benefit = 21 avoided derailments. | No change | Existing measure well proven. Effectiveness considered to very tightly constrained around reference value. Small positive variation applied<br>Application scope – no significant variation likely |

| Measure | Max Potential Benefit (Ref) | Net benefit (Ref) | Sensitivity (Eff.min) | Sensitivity (App.min) | Justification / Comment |
|---|---|---|---|---|---|
| **P-18 & P-21 Track Geometry** | Max: 129 avoided derailments | 58 avoided derailments | No change | 10% cost decrease in year 1, and subsequent years. Hence €153 mill and €76 mill respectively. | Effectiveness no change from reference value.<br>Application scope – amount of track requiring additional attention estimated. |
| **P-19: Clearance of Flange Groove** | Not modelled. We consider that we have already applied optimistic parameters and shown this measure to be able to be discarded without further consideration. | | | | |
| **P-28: Polyamide Roller Cages** | 44 avoided derailments | 33 avoided derailments | Measure effectiveness increased to 85%. New net benefit = 37 avoided derailments. | 50% decrease in brass roller cages (1.3 million) | Effectiveness unproven scientifically, reflected in reduction in this parameter.<br>Application –decrease in quantity of brass roller cages |
| **F-6: Anti-lock Devices** | Not modelled. We consider that we have already applied optimistic parameters and shown this measure to be able to be discarded without further consideration. | | | | |
| **F-7: Sliding Wheel Detectors** | 8 avoide8d derailments | 7 avoided derailments | Measure effectiveness reduced to 95%. New net benefit = 8 avoided derailments. | No change | Existing measure well proven (although not in Europe). Sensitivity value selected to reflect unproven in Europe.<br>Application scope – no significant variation likely |
| **M1- Derailment Detection** | N/A | N/A | Measure effectiveness increased to 95%. | No change | We believe the measure is effective with little variance. Small positive variation applied.<br>Application scope – unchanged. |

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