Development of the Future Rail Freight System to Reduce the Occurrences and Impact of Derailment

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D-RAIL

Collaborative Project (CP)

D1.1
Summary report and database of derailments incidents

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Executive Summary

D-Rail - WP 1 has gathered information on numbers of derailments and their causes from countries in Europe and around the world, and associated costs where available. The objective is to identify the major causes of derailment as a starting point for the detailed analysis of derailment causes in WP3.

Previous derailment studies are also looked at. Different countries have different categorisation of causes, and generally different thresholds for reporting, which makes direct comparison difficult. Where human factors are considered, as in UIC and RSSB, these have a significant impact.

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

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

Breakdown of derailments into causes, and rankings of these causes, are presented both for European countries (in particular Austria, France and Great Britain, with the DNV / ERA results for comparison) and as a comparison between Russia, the USA and DNV / ERA (representing Europe). Alternative approaches to comparing and ranking causes are also presented, i.e., normalising the number of derailments by the amount of cargo transported, and using the cost of derailments for each category as a share of the total cost.

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

This review includes information about monitoring systems.

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

Derailment impact will be studied further and presented in Deliverable D1.2.

Contents

Glossary

Term	Description
DDD	Derailment Detection Device
DG	Dangerous Goods
DNV	Det Norske Veritas
ERA	European Railway Agency
ERADIS	European Railway Agency Database of Interoperability and Safety
ERTMS	European Rail Traffic Management System
EU	European Union
EUROSTAT	Eurostat is the statistical office of the European Union
GB	Great Britain
HABD	Hot Axle Box Detector
I	Infrastructure
KVB	Contrôle de Vitesse par Balises ('Speed control by beacons')
O	Operations
RAIB	Rail Accident Investigation Branch (in GB)
ÖBB	Österreichischen Bundesbahnen
RFID	Radio Frequency Identification
RGS	Railway Group Standard
RIV	Regolamento Internazionale dei Veicoli (International Wagon Regulations)
RS	Rolling Stock
RSSB	Rail Safety and Standards Board
SMIS	Safety Management Information System (GB accident database)
UIC	International Union of Railways

1 Introduction

The D-RAIL project aims to significantly reduce freight derailments in the future, through improved understanding of the causes of derailment and the methods for anticipating derailment through measurement of appropriate system parameters. Of course, D-RAIL is not the first project with this aim, and the results of past projects will be a major input. However, the focus in D-RAIL is more on the underlying causes of derailment, and on cases where multiple factors conspire to cause a derailment even when all system parameters are within tolerances, for example, higher than usual speed combined with a slight track twist.

Work Package 1 of D-RAIL will provide a comprehensive review of freight derailments over the period of 2005-2010, in order to identify not only the most common causes of derailment but also combinations of causes. This builds on the recent work by DNV for the European Rail Agency (see Section §2), as well as past studies by UIC, and by the Rail Safety & Standards Board (RSSB) of derailments in the UK.

The structure of WP1 is illustrated in *Figure 1.1* This WP will produce two deliverables. Deliverable D1.1 provides a summary and database of derailments with the focus on identifying the most common causes and combined causal factors; these results feed into Work Package 3 which will model and analyse derailment causes in greater depth. Deliverable D1.2 will focus on the costs of derailments and their economic impact; these results will feed into Work Package 2 which is forecasting freight demand as far ahead as 2050 and will identify future challenges such as: increased axle load, increased traffic, and increased speed.

Section §4 gives an overview of recent derailments and an analysis of their causes. D-RAIL is a project within an international consortium, and has access to derailment data from databases in Russia, the USA, the UK and Austria, as well as UIC's database.

Section §5 discusses vehicle, infrastructure and operational parameters and secondary causes and contributing causes. It has a section on combined causes and shunting yard derailments.

Section §6 provides measuring techniques available in partner countries.

Sections §7 and §8 give conclusions and recommendations for the in-depth analysis of derailment causes in Work Package 3.

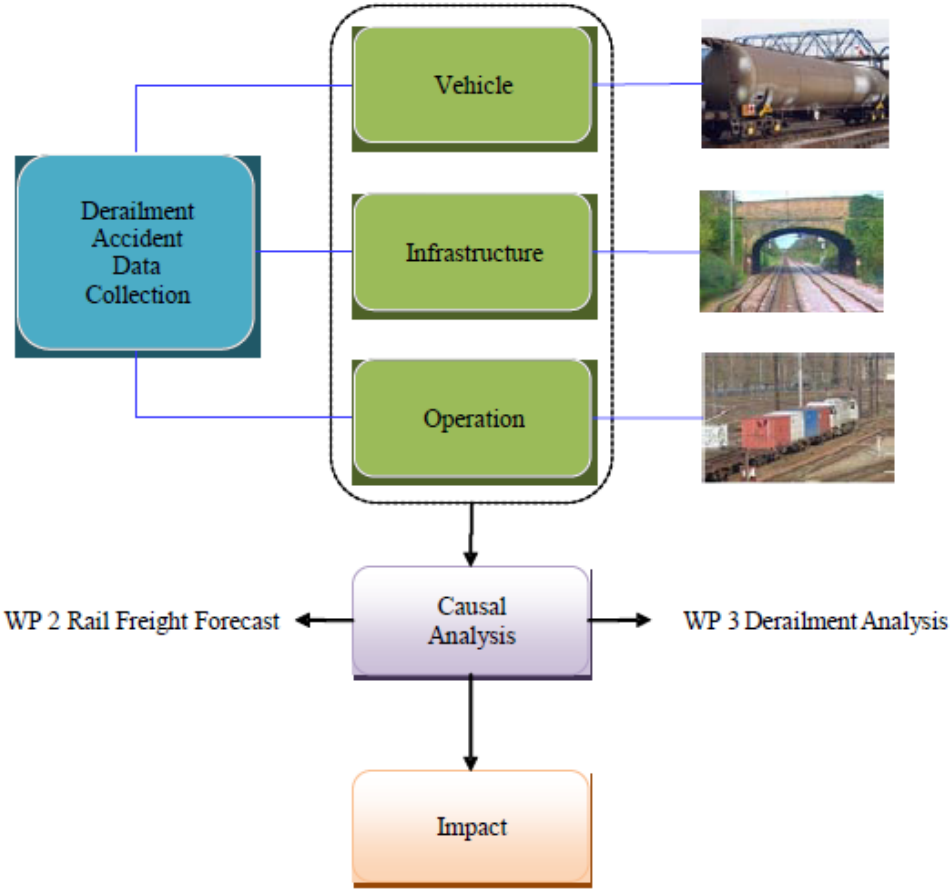


Figure 1.1 WP1 - Approach to Derailment Impact

2 Review of past derailment studies

2.1 Introduction

The European Railway Agency (ERA) was established to provide the EU Member States and the Commission with technical assistance in the fields of railway safety and interoperability, (http://www.era.europa.eu). In 2009 (ERA) identified that substantial benefits for quality of service and safety of the railway freight transport may be achieved by a significant reduction of freight train derailments. It is also considered that small or fragmented improvements of existing safety measures might be neither significant nor sustainable in regard to the foreseeable evolution of railway freight transport, as described in 'A sustainable future for transport' [COM(2009) 279/4], and the expected increase of railway traffic.

The problem is significant – 691 freight train derailments have occurred within the EU over the last 10 years (roughly 1999-2009). From a sector economic perspective it was estimated that the open line freight train derailments in EU 27 cost more than 200 million Euros per year, and are almost entirely related to infrastructure and rolling-stock damages as well as operation disruption impacts (ERA/REP/03-2009/SAF).

This Chapter presents brief overview results of several previous reports concerning derailments before the start of the D-rail project, completed by ERA (DNV), UIC and RSSB. The purpose of this background research for the D-Rail project is to assist in choosing the right methodology, selecting the definitions of causes and looking at previously researched derailment influential causes. It also provides previous derailment analysis for comparison with our results.

The basic review structure for each study is:

- What was the study about, who wrote it and for whom?
- Data source
- Results and analysis from the study, e.g. main derailment causes.

2.2 ERA (DNV) study

The European Railway Agency (ERA) commissioned a study with the title: "Assessment of freight train derailment risk reduction measures" from 'Det Norske Veritas' (DNV[1]), which was completed in 2011.

This study concentrated on risk assessment, whilst the D-rail project has more of an engineering approach. The D-rail project overlaps with the DNV study, but provides more detailed analysis.

DNV looked at data from 27 EU countries, Norway and Switzerland and analysed only 201 of the selected accidents. DNV accidents data range from 1996-2009. (Source DNV Part A, Final report).

The breakdown of freight derailment causes by DNV is shown in *Figure 2.1*.

[1] DNV is an independent foundation, a consultancy firm and a global provider of services for managing risk (http://www.dnv.co.uk/).

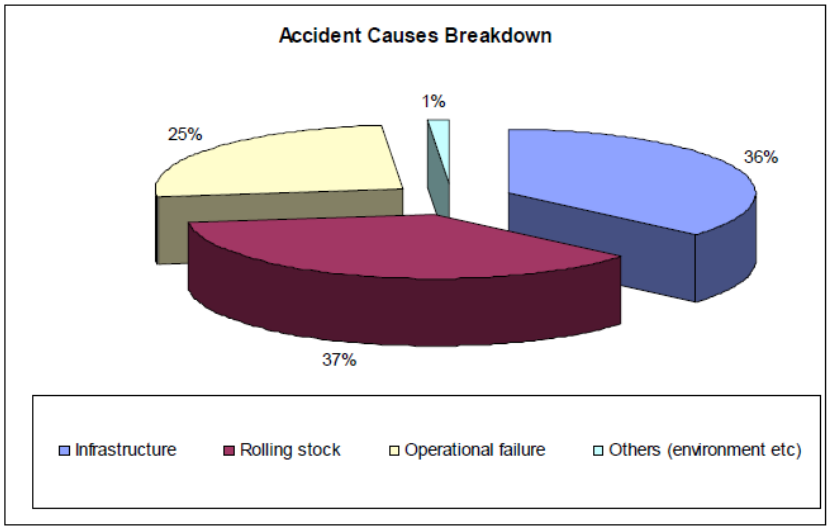


Figure 2.1 Approximate Breakdown of Freight Train Derailments by Category (Figure 12 from DNV Part A Final report)

Within the infrastructure category, track geometry is the dominant cause accounting for 70% of the total. Within the rolling stock category failure of axles is slightly over 40% of the total. Operational failures are more evenly spread with 'other' representing 25% of the total.

The DNV report does not give much information about the costs; particularly break down of costs for each accident. The Final B2 report suggests costs following derailment associated with impact on the railway system and operations; see *Table 2.1* below.

Table 2.1 Railway System and Operational Costs

	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

According to DNV simulation models, they estimate the following:

- Total cost of freight train derailments = Euro 505 million. (This may vary between Euro 195 million and Euro 701 million)
- Average cost per freight train derailment = Euro 1.01 million. (Ranging between Euro 390,000 and Euro 1,402,000).
- Number of fatalities = 3.9 (resulting mainly from incidents in which there is a release of DG).
- Major cost impact relates to operational disruption.

The Report goes on to suggest that "The principal future use of the DNV impact model is the calculation of benefits that may be achieved through the implementation of new measures."

2.3 UK past derailment studies and reports

Since 2003 RSSB has commissioned four research projects on behalf of the rail industry in Great Britain in relation to derailments. They are:

- T078 Derailment mitigation - Categorisation of past derailments (2003).
  This research analysed derailments over a 10-year period as a first stage towards identifying the underlying causes and the standards which currently control these factors.

- T207 Development of a prototype model for managing derailment risk due to track faults (2004).
  By developing a prototype, this research aimed to assess the feasibility of developing a model that would enable Network Rail to manage the risk of derailment due to track faults.

- T357 Cost-effective reduction of derailment risk (2006).
  This work sought to understand the cause of derailments that occur where both vehicle and track appear to comply with standards and the means of reducing the risk of these occurrences.

- T682 Developing the incident cost model (2007).
  This research developed a prototype railway industry incident cost model based upon previous research into safety critical communication errors, but also covered a wider range of railway events such as collisions and derailments.

A brief summary of each project follows.

<u>T078 Derailment mitigation - Categorisation of past derailments</u>

The specific objectives of this project were to:

- Categorise the derailments that occurred during the 10 year period 1992-2001.
- Divide the categories into those derailments that involve non-compliance with relevant Railway Group Standards (RGSs) and those that might have occurred even though track and vehicles were compliant with relevant RGSs (i.e. those that are not adequately controlled by RGSs).
- Develop an understanding of those derailments that are not adequately controlled by RGSs and where initial evidence suggests that both the vehicles and the track were compliant with current mandatory requirements, through:
  - Identification of the number and nature of those derailments, and analysis of the causes.
  - A search for and review of documentation on subjects related to the causes of these derailments and an assessment of the documents most relevant to this project.
- Identify, using an analytical approach, the risks associated with any inadequacies of the relevant RGS.
- Develop control measures for the risks.

Findings

A database containing information on the 1657 derailments identified during the 10 year period 1992-2001 was created. The database contains information from a variety of sources, notably AEAT Rail's derailment database, SMIS and the RSSB Inquiry report database.
This work identified significant variations in derailment data quality and consistency of reporting which was reported to have become noticeably worse since SMIS was introduced and AEAT Rail stopped formally collating derailment data.

The research successfully categorised 85% of these derailments into one of three categories.
Category 1 derailments (vehicle or track non-compliant with standards)

There were 524 Category 1 derailments in the 10 year period.

- 91% of incidents were caused by track which was out of standards, although in 17% of these incidents vehicle or operational factors contributed to the derailment.
- 8% of incidents were caused by vehicles which were out of standards (principally due to poor suspension condition).
- 70% of incidents involved freight trains.
- 12% of incidents involved vehicles with a known susceptibility to derailment interacting with cyclic top or twist faults.

Almost all the Category 1 derailments would have been prevented by:

- Eliminating track twists worse than 1:150
- Repairing poor lateral restraint (which leads to gauge spread)
- Ensuring general S&C condition (and switch blade condition in particular) is maintained to standards
- Ensuring derailment-prone vehicles are maintained and operated correctly.

Category 2 Derailments (vehicle and track compliant with standards)

There were 169 Category 2 derailments over the 10 year period.

- 21% of incidents were caused primarily by track issues (mainly rail breaks which are considered to be better controlled now)
- 17% of incidents were caused primarily by vehicle issues (mainly axle/ wheel/journal failures which are also considered to be better controlled now)
- 27% of incidents were caused primarily by operational issues (mainly traction/braking shocks and poor loading)
- The remaining 35% of incidents were caused by interactions between track and (mainly derailment-prone) vehicles:
    - Failing to negotiate poor track twist at low speed, and
    - Failing to negotiate poor track top (and often other track faults) at high speed.

Almost two thirds of the Category 2 derailments would have been prevented by:

- Identifying rail breaks before they cause a derailment
- Identifying axle/wheel/journal failure before they occur in service
- Eliminating combinations or poor track top, twist and alignment
- Ensuring derailment-prone vehicles are maintained and operated correctly.

The research identified that

- There is a need for quicker and better identification of track faults.
- There is a need to identify and prioritise track faults which increase derailment risk. This is particularly important when considering combinations of less severe track faults.
- There is a need to consider additional mitigation measures following the identification of track faults (in particular twists worse than 1:150).
- There is currently no requirement to go back and check recent work after traffic.
- There is a need to review how vehicle derailment resistance and track standards fit together.
- There is also a need to review how the vehicle track force limits and track standards fit together.
- Vehicle loading has been identified as a primary cause in derailments. The definition and clarification of acceptable loading practice, coupled with enforcement of these requirements would ensure a significant reduction in derailment risk.

T207 Development of a prototype model for managing derailment risk due to track faults

Introduction

This research project considered the feasibility of developing a risk model capable of describing the complex interactions that create and mitigate the derailment risk due to track faults. A detailed risk model of derailment would aid the understanding and management of the interactions that contribute to derailment and would also help answer the following questions:

- What are the risk levels, and key risk contributors, associated with a range of different track faults across the UK rail network?
- How does this vary at specific locations or at locations with common characteristics (for example, in tunnels, on different categories of track)?
- What impact would changes to the type and condition of assets have on risk levels?
- What are the effects of changing control measures (some of which deal with a particular fault, others being more general) on the risk profile?

The main track faults which have been identified as forming the core of the model include; broken rail, broken fishplate, gauge spread, track twist, track buckle and cyclic top. Based around this core, the overall model consists of three modules:

1. Environment Module – Defines the range of track/vehicle characteristics for which derailment frequencies are calculated for each fault under consideration
2. Fault Module – Models frequency of line speed and reduced speed derailments, given environment characteristics, for each fault under consideration
3. Consequence Module – Models consequences of derailment for scenario defined by route followed through the ‘Environment’ and ‘Fault’ modules.

Findings

A prototype derailment risk model based on spread gauge track faults was developed successfully giving a high level of confidence that a full model could be developed. A meeting with industry representatives at the end of the project suggested that future development should concentrate on track geometry faults rather than the derailments due to broken rails that are already analysed and modelled in some detail. The background to the project and the development of the prototype model is described in detail in the project report.

For each analysis option that the user runs, the following results will be provided for each environment cut set:

- The cut set probability of occurrence
- Fast and slow derailment frequencies (for each track fault and total values)
- Consequence and total risk values (for fast and slow derailments for each track fault and total values)

The model will feature the ability to save results produced from different runs. It also stores the results obtained from running the base data so that direct comparisons can be made between current risk levels and results obtained from modelling alternative situations/assumptions.

T357 Cost-effective reduction of derailment risk

Introduction

Risk Solutions were commissioned to carry out a detailed review of Category 2 derailments. Particular attention was to be given to those derailments in which the control of the realised risk depended on compliance with reciprocal (or complementary) measures on each side of the vehicle/track interface.

Findings

High Speed Derailments

Two mechanisms tend to occur at higher speeds (over 30 mph):

- ‘Cyclic Top’ derailments ‘Top/Twist/Alignment’ derailments

Low Speed Derailments

Two mechanisms tend to occur at lower speeds (below 15 mph):

- ‘Switch Blade’ derailments
- ‘Twist’ derailments

Additional Factors

Poor loading was the most common principal factor across the 42 derailments considered, being implicated in 25% of incidents. It also played a part in around 30% of ‘Top/Twist/Alignment Combination’ derailments.

Successfully addressing vehicle loading would have a significant impact on reducing Category 2 derailments.

Poor track geometry was always involved in some way in the derailments studied. In particular, poor top and twist are the biggest contributors to these types of incident. Early identification and rectification of these top and twist faults would have a major impact especially on those derailments that are high speed and high impact incidents, such as 'Top/Twist/Alignment Combinations' or 'Cyclic Top.'

In addition, rapid deterioration in track quality was a common feature, which suggests that improving the management of both temporary and permanent increases in traffic levels to ensure that adequate levels of inspection and maintenance are being carried out would reduce the occurrence of these types of incident.

T682 Developing the incident cost model

Introduction

A simple cost model was developed as part of project T365 'Collecting and analysing railway safety critical communication error data', which dealt with communication errors. The model demonstrated the indicative costs of such errors. The work was reviewed by the Safety Critical Communications Focus Group (SCCFG) who concluded that it could be a really useful tool if further developed to provide more accuracy in relation to the costs arising from such incidents.

Findings

The cost of the incidents varied from ~£1k to more than £220k with an average of ~£16k: All incidents had a range of different consequences and hence contain various cost types, however it is worth noting that none of the costs involved included more than minor infrastructure damage or delay to a small number of trains. The seven incidents with the highest costs (those exceeding £50k) tended to be dominated by one cost – usually T&RS damage but, in one case, the cost of delays was estimated to be as high as £200k.

A number of these costs are routinely quantified, such as the cost of delays and damage to rolling stock, because they result in payments between industry players. Other costs, such as people costs and the cost of investigations, are often 'hidden'. When considering these two cost areas alone, the average 'hidden' cost over the 100 incidents was £5.8k with the cost approaching £30k in some cases.

RSSB Annual Safety Performance Reports.

According to the 2010/2011 Report, causes of all derailments are spread as in Figure 2.2. Track failure and irregular working are responsible for quarter of derailments each. Within the track category the major causes of derailments are track gauge spread and switches and crossings.

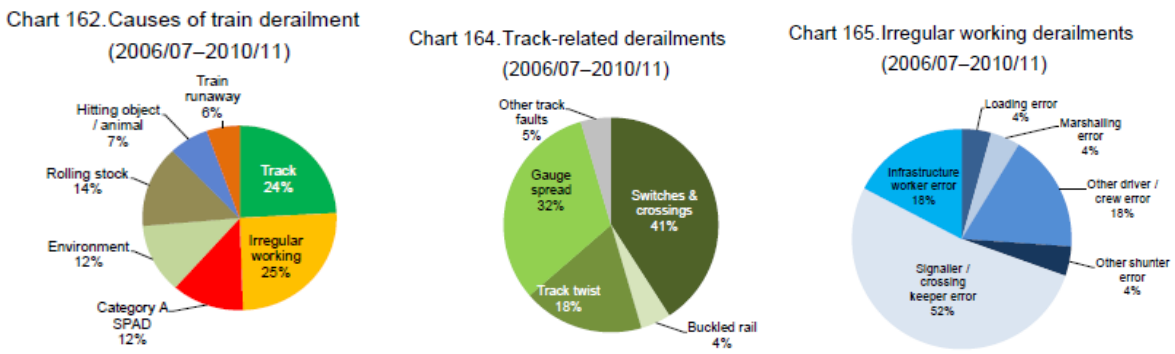
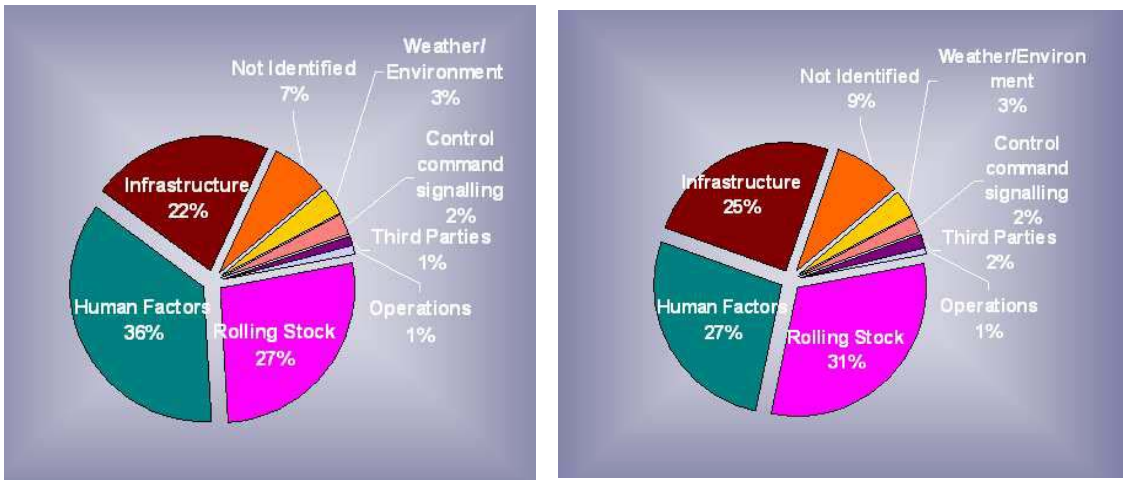


Figure 2.2 Causes of derailments in UK. [Rail Safety & Standards Board Annual Safety Reports 2010/11]

2.4 UIC and ERRI past studies and reports

The main statistical information on derailments from UIC comes in annually published Safety Database Activity Reports. The latest one was for 2010, published in December 2011. Section 2 of the report concerns analysis of derailments for both passenger and freight trains. The proportion of freight train derailments is the highest and increased in 2010 compared to 2009, both in number and percentage from 44% to 57% in 2010. The indicative reason for this being the fact that freight trains are often longer, carry heavier loads, and often run on lines that are not as well maintained. They suggest improvement in maintenance, inspection and operations of both freight lines and rolling stock.

Causes of derailments for all trains for 2009 and 2010 are presented in *Figure 2.3*.



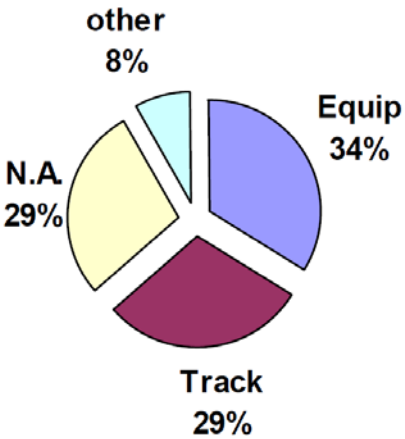
a) 2009 b) 2010

Figure 2.3 a) First-level causes of derailments in 2009 b) First-level causes of derailments in 2010

Additionally UIC (ERRI) has a selection of reports in Project B 55: “Prevention of derailment of goods wagons on distorted tracks,” where analysis was conducted on how track twist, curve, wheel-loads and combined causes influence derailments.

2.5 Canadian **past derailment study**

TranSys Research Ltd prepared a study in 2007 named: "*Causes of accidents and mitigation strategies"* for the Canadian Railway Safety Act Review Secretariat. Review of Canadian railway derailment accidents and incidents where equipment or track safety performance was an issue was among the objectives of the project. The analysis was focused on mainline derailments in the interval 1999 to 2006. The overall distribution of the number of mainline derailment causal factors, over the entire 7 year interval, for Class 1 railways is illustrated in Figure 2.4.



Four types of derailments are shown:
(Equip)– those related to an equipment component,
(Track) - those related to track components,
(N.A.) - those with no safety factor available in the data,
(other)- all other derailments with a non-track, non-equipment factor cited.

Figure 2.4 Average distribution of causal factors cited (1999-2006), source "Causes of accidents and mitigation strategies"

The findings of study derailment causes are:

- Two of the largest contributors to derailments are wheel and rail failures (35% of coded mainline derailments).
- In the rolling stock (equipment) category axles/wheels contribute to 49-54% of derailments, followed by body/coupler components 23-26%. (Note: difference in percentages is due to different sources of reporting).
- In the infrastructure (track) category geometry contributes to 43% of derailments followed by rail failures (31-37%).

2.6 Summary of past derailment studies

Previous derailment studies are reviewed in this Chapter. Different countries have different categorisations of causes, and generally different thresholds for reporting which makes direct comparison difficult. Where human factors are considered, as in UIC and RSSB studies, these have a significant impact. Some general grouping of causes however can be done, see Table 2.2.

Table 2.2 Grouping of derailment causes from past studies.

Cause main categories	DNV/ERA	RSSB	UIC	Canada
Infrastructure	36%	24%	27%	29%
Rolling stock	37%	14%	31%	34%
Operation and human factors	25%	43%	28%	29%
Other (Environment, third party, etc.)	1%	19%	14%	8%

Looking at the technical causes of previous studies, it would appear that Infrastructure still presents a major problem, with both track geometry and rail quality. More research is required in rails for developing new rail materials, and in understanding its behaviour under different loads and environmental conditions. In Canadian rolling stock, axles/wheels contribute to 49-54% of derailments, followed by body/coupler components.

3 Data sources and country specifics

Data about derailments exist both in European and in individual country databases. They belong to a variety of organisations and are presented in a number of formats differing in structure, information under which criteria is reported and the definition of causes of accidents, etc. Some are public and some are not. This study compares both European and international derailment data and principal sources of information include:

- European ERADIS (DNV) safety database
- European UIC safety database
- USA (FRA) safety database and investigation reports
- Russia safety database
- GB Safety Management Information System (SMIS) administered by RSSB and RAIB investigation reports
- Austrian safety database and investigation reports
- France SNCF safety database
- Germany DB safety and event database

3.1 Europe

3.1.1 European databases

Improving safety on European railways is an on-going aim of all member countries. According to European regulations, each state should report serious and significant accidents occurring on their territory, with causes leading to accidents, etc. Data gathering is still not at a satisfactory level, but it does give an indication of safety issues and costs. The major problems are:

- 3 existing European databases (and forms for gathering data): ERADIS (http://pdb.era.europa.eu/), EUROSTAT (http://ec.europa.eu/eurostat) and UIC;
- Definitions and terms are not uniform throughout Europe;
- Each country has several bodies working on statistics, analysis, reports;
- Countries are not submitting data to databases on time and in full.

ERADIS: The ERADIS database, documents and reports are in the public domain and for Europe ERA is the best source of accident information. ERA's main task is data gathering, monitoring and analysing safety which can be seen in their ERADIS database. The Railway Safety Directive (2004/49/EC) requires reporting data to ERA and from each country there are 2 reporting bodies: The national investigation body (NIB) which sends investigation reports on all serious accidents, and The National Safety Authority (NSA) which reports all significant accidents. Main causes in this database are divided as: infrastructure, rolling stock, operations and third parties. Costs are not always reported.

EUROSTAT: This database is public and contains information about accidents. Data collection on goods transport, passenger transport, and on rail accidents is mandatory based on Regulation EC 91/2003. Freight data from 1982 to 2002 is based on Directive 80/1177/EEC and more information about data collection for EUROSTAT can be found at:

http://epp.eurostat.ec.europa.eu/cache/ITY_SDDS/EN/rail_ac_esms.htm.

The database does not include accident cost, just numbers which represents passenger and freight totals, i.e. there is no option of separating them by cause or type of train. However separate statistics were gathered for a number of accidents involving the transport of dangerous goods. For these reasons derailment data from this database was not considered for this report, although data for cargo volume was used.

The UIC Safety Database contains information on all railway accidents from 21 member European countries, since 2001. Information is submitted on voluntary basis and costs of accidents are not reported. The database contains information about accidents including derailments which had at least one of the following consequences:

- 1 or more fatalities;
- 1 or more serious injury;
- Physical damage more than 150 000 Euro
- 6 hours of traffic interruption.

Limited access to a confidential database version is available to Members at: http://safetydb.uic.org/spip.php?article1. The Annual 'Safety Database Activity Reports' are available to the public and can be downloaded from: http://safetydb.uic.org/spip.php?article2.

A summary of the top UIC derailment causes for 2005-2010 include:

- Fault On Wheel or Axle
- Track Deformation
- Weather & Environment
- Interaction Infrastructure/vehicle
- Human Factors
- Train driver
- Broken Rail
- Traffic Operating Staff
- Switch Failure
- Gauge, Shifted Load (vehicle Defected)

3.1.2 Europe operations specifics

European rail transport has to overcome differences between countries in technical design of infrastructure and vehicles, level of maintenance, and differences in operations. In addition to differences between countries, European transport is led by numerous, often international companies. National railway companies are usually split into separate entities for infrastructure, passenger and freight operators, various maintenance companies. In freight, there are hundreds of train operators that either run their own wagons or lease them from freight wagon leasing companies.

The European network generally has a 'normal' gauge of 1435mm, while Spain and Portugal and ex- Soviet Union states have 'wide' gauges of 1520mm or 1668 mm. Some are dedicated passenger or freight lines, but most have mixed traffic. Not all lines are electrified and voltages differ, sometimes within the same country. In general this makes cross border travel more difficult. Typical maximum axle load in

Europe is 22.5t, and maximum freight speed is 120km/h in most cases. Some infrastructure, usually ore lines, are designed and maintained for higher axle loads. In Sweden heavy haul transportation with axle loads up to 30 t is well developed. For trains crossing borders and running on the European networks wagons are required to meet RIV technical agreements and regulations.

3.2 USA - Overview of US Derailment Data

3.2.1 USA data sources

US derailment data is gathered by the US Department of Transportation, Federal Railroad Administration (FRA) and stored on their accident and derailment data base. The data consists of all derailments from all US freight railroads that exceed the FRA reporting threshold - currently in the region of $9,000. Note this threshold applies only to the cost of damage or repair of the rolling stock (locomotives and wagons) and infrastructure (track, signalling, etc.). It does not include value of the goods lost or damaged, nor does it include costs associated with train delays, rerouting of traffic, etc. Other studies in the US suggest that the actual cost of a derailment is approximately twice that of the FRA reported cost when these other factors are considered.

It is noted that US railroads are required by law to report all accidents and derailments above the reporting threshold to the FRA.

The primary accident/derailment categories are:

- Equipment
- Operations
- Track
- Signals

A summary of top 10 USA derailment causes include:

- Rail defects/failure
- Track geometry defects
- Wheel failure
- Axle and Bearing Failure
- Frogs, Switches, Track Appliances
- Train Handling and Makeup
- General Switching Rules and Switching Operations
- Improper Use of Switch
- Road Bed Effects
- Speed

3.2.2 USA – country operations specifics

The USA's rail network is of mixed traffic where both passenger and freight operate on the same lines. The USA has significantly higher axle loads than in operation in Europe and Russia. Standard "free interchange" axle loading in the USA (and in North America in general) is 33 tonnes (36 tons) on 914 mm (36") diameter wheels.

This combined with very heavy unit train operations (12,000+ tonne trains) results in a significantly high level of rail loading.

3.3 Russia

Russia maintains investigation reports which are not publicly available. According to Russian legislation all accidents and incidents on railway transport should be investigated by a special committee. For the D-Rail project data on derailments was gathered directly from these reports and used to populate the D-rail database. Data contained only mainline derailments and were classified per single cause with information about number costs, causes of derailments and consequences of derailments.

3.3.1 Russia – country operations specifics

The Russian Railways operate over 86,000 km (53,000 miles) of common carrier routes – 43,100 km of which are electrified. Russian's rail network is a mixed traffic railway where both passenger and freight traffic operate on the same lines. The inclusion of several hundred kilometres of industrial routes makes it the second largest network in the world exceeded only by the United States.

The railway operates in a number of climatic zones with extreme temperature changes. The network has a broad gauge of 1520 mm, with an axle load of 25t and freight speeds of 90km/h.

Russian Railways transport in the region of 1.1 billion tonnes of cargo annually.
At the end of 2010 the number wagons independent from Russian Railway operating companies amounted to about 508 thousand units (49.5% from the total fleet). In general, the holding company 'Railways' share of freight cars on 31 December 2010 amounted to 50.5% of the total car fleet.

In 2010 the Russian fleet of freight cars increased by 3.4% and amounted to more than 1,025,000 cars (31.12.2009 - 991 thousand cars).

By 31 December 2010 Russian Railways had more than 212 thousand cars, or 20.7% of the total Russian fleet. At the end of December 2009 the share of Russian Railways had been 34.1% (Park JSC "RZD" - 337.9 thousand cars).

There is an increase in the number of privately owned wagons in Russian with the share of Russian Railways fleet comprising 29.7%, and independent private ownership reaching 49.5% of the total fleet (compared to 23.9% and 41.9% respectively at the end of December 2009.

Private companies have the following percentages of these major types of wagons: other (specialized) wagons (36.0%) covered wagons (7.9%), tanks (8.9%) and platforms (2.5%).

Since July 2011 all rolling stock has been transferred to operating companies and currently there are 1800 wagon owners in Russia. Rail freight is provided by private freight train operating companies and Freight services are provided by the Freight Operating Company – the owners of freight wagons fleets. RZD provide traction and

infrastructure and in some cases modal transfer and product loading/unloading facilities. Logistics Service Providers (LSPs) often act as intermediaries between shippers and freight operating companies.

Top Russian derailment causes:

Per cost	Per number
Failure of bogie structure and supports	Failure of bogie structure and supports
Excessive track width	Excessive track width
Subsidence	Failure of rail support and fastening
Rail failures	Human factors
Failure of rail support and fastening	Hot axle box and axle journal rupture
Excessive track twist	Twisted or broken wagon structure/frame
Weather, Environment & 3rd Party	Excessive track twist
Twisted or broken wagon structure/frame	Spring & suspension failure
Brake component failure	Brake shoe or other object left under train
Hot axle box and axle journal rupture	Rail failures
Axle ruptures	Switch component structural failure

3.4 Great Britain

3.4.1 GB data sources

In the United Kingdom (UK) and Great Britain (GB) there are several organisations that compile railway safety statistics analysis and reports:

- RAIB (Rail Accident Investigation Branch) is an independent railway accident investigation organisation for the UK and acts as UK's NIB. (http://www.raib.gov.uk/home/index.cfm)
- ORR (The Office of Rail Regulation) is the independent safety and economic regulator for Britain's railways. (http://www.rail-reg.gov.uk/)
- RSSB (Rail Safety and Standards Board) is a not-for-profit company owned and funded by major stakeholders in the railway industry (such as infrastructure managers, passenger and freight operating companies), in GB (not the UK) and is independent. It also receives grants for research from the Department for Transport to conduct research on behalf of the industry (www.rssb.co.uk). RSSB is responsible for the SMIS database.

SMIS Database

Great Britain uses a system called the 'Safety Management Information System' (SMIS) to collect safety data on behalf of the GB rail industry. The system was introduced in 1997 and now contains over 1.8 million safety related records. It is used by approximately 40 GB railway organisations and its use is mandated in GB Railway Group Standards (RGS) to record safety events. As such SMIS is the GB rail industry's main source of safety performance monitoring data. It is maintained and managed by RSSB on behalf of GB rail industry members.

SMIS allows the GB rail industry to meet its UK legislation reporting requirements and records data relating to:

- Fatalities
- Major injuries
- Reportable and non-reportable minor injuries
- Shock/trauma
- Train accidents and incidents
- Near misses and some precursors
- Safety related defects
- Investigations and recommendations

All railway group members in Great Britain are required to record any derailment event with SMIS. This includes any derailment of:

a) A train or rail vehicle on a running line, including a derailment that occurs:
   i) While the line is blocked due to a previous accident or emergency.
   ii) Occurring within a possession, including work sites within a possession.
   iii) Occurring during a shunting operation.
b) A train in a siding that results in a running line being physically obstructed.
c) A train in a siding that is part of the Network Rail Managed Infrastructure.

In addition to the above mandatory requirement, GB Railway Group Members also use SMIS to record similar derailment events in yards, depots and sidings that occur:

a) While the line is blocked due to a previous accident or emergency.
b) Occurring within a possession, including work sites within a possession.
c) Occurring during a shunting operation.

However, it is not a mandatory requirement to record derailments in yards, depots and sidings and so this data should be considered limited and is not included in the summary figures in this section.

Each derailment is recorded against an immediate cause category description. These categories have been used to allocate GB SMIS derailment events to the appropriate standard D-Rail cause categories.

RAIB Investigation reports: The RAIB produces a report on every accident and incident that has been the subject of a full investigation. Reports are published at: http://raib.gov.uk/publications/investigation_reports.cfm.
These reports were used as additional information about derailments occurring in GB, especially for looking at causes. Each report sets out the facts of the occurrence, describes the investigation process and the evidence gathered, provides an analysis of the events surrounding the accident and sets out the RAIB's conclusions and recommendations.

RAIB also has immediate cause database where all accident reports are classified according to the cause.

3.4.2 GB – country operations specifics

Britain's rail network is a mixed traffic railway where both passenger and freight traffic operate on the same lines. Freight traffic in terms of kilometres travelled is approximately 10 per cent of the rail network total, but when its weight factor is adjusted then it increases to around 30 per cent. In terms of trains per day there are some 1,000 freight trains and around 19,000 passenger trains. On this measure freight is five per cent of the total, but the freight journeys will be longer which comes back to the 10 per cent number quoted above.

In the UK, rail freight is provided by private freight train operating companies. Freight services are provided by Freight Operating Companies (FOCs). They provide traction and rolling stock and in some cases also modal transfer and product loading/unloading facilities. Additionally, Logistics Service Providers (LSPs) often act as intermediaries between shippers and freight operating companies.

Rail freight operators
There are four main rail freight companies currently operating in the UK. They are:

DB Schenker is the largest freight operator overall. It is organised into four main divisions.

- Network: for intermodal and logistics services
- Energy: coal haulage for the electricity supply industry
- Industrial: movement of heavy raw materials for industry such as metals and petroleum
- Construction: for the construction and waste industries

Freightliner is the largest operator in the container market. It has two divisions.

- Freightliner International: the traditional intermodal container business
- Freightliner Heavy haul: the developing coal and bulk products haulage division of Freightliner Group

DRS (Direct Rail Services) is a wholly owned subsidiary of the Nuclear Decommissioning Authority. Although set up at the time of rail privatisation to ensure the continued ability to haul spent nuclear fuel from the nuclear power station decommissioning programme, this now accounts for only 40 per cent of its business. DRS has diversified into domestic intermodal and retail traffic, much of it newly won to rail.
GBRf (GB Rail Freight) provides both intermodal container and bulk coal haul services in addition to specialist infrastructure freight services.
Europorte Channel provides services between France and the UK through the Channel Tunnel.

Other smaller rail freight companies such as Colas Rail and Mendip Rail have also started operation in Britain. This has all led to a competitive market with investment in excess of £1.5 billion in over 400 new locomotives and 3,000 wagons to meet customer demands and growth since the late 1990s.

Network Rail is the owner and operator of the commercial track infrastructure in Great Britain. This includes connections to over 700 private sidings and over 350 sites and depots leased to freight train operators. The Channel Tunnel and associated rail routes such as High Speed 1 are separately owned.

The ORR (Office of Rail Regulation) is responsible for issuing licences to freight train operators and considers track access agreements and charges between freight train operating companies and Network Rail.

The amount of freight moved in 2010-11 was 19.23 billion net tonne kilometres, a 1.0 % increase from 2009-10. During 2010-11 for the first time consumer rail freight traffic was greater than coal traffic. Despite the recent economic downturn, rail freight volumes grew by 2% between 2006 and 2011, and over the same period, consumer rail freight grew by 29%.

30 per cent per cent of the traffic carried on the British rail network is freight. Rail freight moves an estimated 43.5 million tonnes of goods to and from the UK's ports. Each day, rail handles up to 1,000 containers moving through the Port of Southampton. Every year rail transports more than a quarter of a million containers through the Port of Felixstowe, carried on 22 freight trains per day.

As well as import (and export) containers, rail is traditionally strong in transporting heavy and bulk commodities. Network Rail forecasts continued growth in container traffic.

The main difference in operation between mainland Europe and Great Britain is that the latter is predominantly trainload traffic which runs at a maximum axle load of 25.4 tonne. It is unlikely that the heavier axle loads causes abnormal derailment risks with the trainload concept resulting in less shunting in yards. Additionally wagons that are normally designed for a particular load and the marshalling of trains result in fewer occurrences of light and heavy wagons mixed within formations – thus reducing derailment risk. The GB fleet is on average younger than the EU average (this being a combination of specific wagons, fewer total number of wagons as a result of introduction of TOPS in the 1970's, and also privatisation resulting in new companies investing in wagons. One negative impact of privatisation of GB railway in the 1990's was a hiatus of track maintenance as Railtrack assumed control. This situation appears to have been resolved by Network Rail but the statistics from 10 years ago would be skewed by poor track quality.

Top UK derailment causes, ranked by using D-rail cause categories:

Ranked by frequency	Ranked by cost
Human factors	Spring & suspension failure
Excessive track twist	Other or unspecified track geometry causes
Switch component structural failure	Excessive track twist
Other or unknown rolling stock derailment cause	Failure to carry out Rules/instructions/Safe System of Working (Human Factors)
Excessive track width	Failure of rail support and fastening
Other infrastructure failure	Excessive track width
Other operational failure	Improper loading of wagon
Other or unspecified track geometry causes	Inadequately performed maintenance task (human factors)
Brake component failure	Other infrastructure failure
Speeding	Switch component structural failure

3.5 Austria

3.5.1 Austrian database

Austria has a national rail accidents database. Most accident reports are also published in German on the internet at: http://versa.bmvit.gv.at/index.php?id=219. For the purpose of this D-Rail study all derailments were classified according to the original Austrian database, and transferred into the DNV format for comparative analysis. Data provided included: number and costs of derailments, causes, location, etc. If accidents had multi-causes they are calculated as a fraction of 1, for example if a derailment had 2 causes, the number allocated to each cause would be 0.5 (2*0.5=1).
Careful statistical interpretation is required due to the low number of derailments on the data base. The main advantage of the small data base, however, is that an in-depth investigation into the details from accident reports is made possible, with the allocation of the main cause being done accurately. Identifying any neglected contributing factors is also possible. Finally measures for derailment prevention can be more easily identified and used for information purposes in WP 3, 4 and 5.

Summary of key Austrian derailment causes

Based on the analysis of Austrian derailments and taking account of their own categorisation, the top derailment causes based on total cost per category, are:

- breakage of massive wheel
- fully connected brake
- suspension spring
- broken axle
- track gauge widening, track distortion
- broken rail
- flooding, undercutting

3.5.2 Austrian operations specifics

In comparison to other countries the so called RoLa wagon ("Rollende Landstraße"), with its' ultra low floor vehicles (smaller wheels, different axle boxes) has a significant market share on some dedicated lines.

ÖBB Infrastructure AG uses a hot box detection system which is able to deal with the geometry of Y25 boogies (the standard boogie for freight vehicles) and the density of location which is also rather high in comparison to other countries.

3.6 France

French data comes from the SNCF internal database (available in electronic file only since 2006) and the UIC database. The SNCF database is not public. A lot of derailments are described in paper file with some major derailment reports available on the BEATT website: http://www.bea-tt.developpement-durable.gouv.fr/les-transports-ferroviaires-r9.html.

Data is reclassified according to the DNV criteria. Analysis of three separate groups (shunting yard single cause, open line single cause and mainline multi-cause) was completed.

Key derailment causes in France include:

- Hot axle box and axle journal rupture
- Track height/cant failure
- Wagon wrongly loaded
- Weather, Environment & 3rd Party
- Rail failures
- Track superstructure unsupported by substructure
- Excessive track width
- Rupture of monoblock wheel
- Failure of composite wheel with rim and tyre
- Spring & suspension failure
- Brakes not properly checked or tested
- Point switched to new position while point is occupied by train

3.7 Germany

DB maintains a database that contains, beside derailments, all other incidents occurring on the German railway network. The database contains data from 1997 and is for internal use only. Detailed data is therefore not available to the public.
Derailments after 2009 are identified with an event code that allows separation of shunting yards derailments and derailments on track.

Data provided for this project include details of: date, location, short description of incident and cause, number of dead or injured persons, cost of derailment, etc. More detailed information about causes or costs associated with impact on the infrastructure, trains, environment or delay is available in reports linked to the database. The storage of an incident is independent on its related costs.

Analysis of the German data show:

- Most derailments of freight trains occur in shunting yards
  e.g. 2010: 286 derailments during shunting trips and 37 during train runs.
- The total number of derailments per year shows a slight downward trend taking considering the ton kilometres transported
- Percentages of derailment causes (based on 2009 and 2010 figures) with respect to main line are:
  - Rolling stock 25 %
  - Infrastructure 19%
  - Operation 25%
  - Environment 10%
  - Not identified 21%
- Percentages of derailment causes (based on 2009 and 2010 figures) with respect to the cost are:
  - Rolling stock 65 %
  - Infrastructure 6%
  - Operation 11%
  - Environment 1%
  - Not identified 17%

The summarized results for Germany are based on derailments with derailment costs above 10 000 €.

4 Derailment Analysis

Derailment accident data was collected from several databases presented in Chapter 3: UIC and DNV (European countries), USA, Russia, Great Britain (SMIS), Austria and France (SNCF). Each database has a different format, criteria for which data is collected and classification of causes. In order to provide a comprehensive review, analysis and comparison it was necessary to organise the data into the same format. DNV classification was used (see Chapter 4.2.2.) as a base with slight modifications. Data from the period 2005-2010 represented the most accurate reporting data with which to work. Additionally investigation reports in this period are more readily available.

Accident data is set up in a database format to capture several aspects of derailment including environment, infrastructure, rolling stock and operation and will form a key platform for the entire project and subsequent analysis and investigation of freight derailments. The database, in excel format includes information about number of derailments, derailment causes, location, costs and monitoring systems.

From the data it was possible to determine key causes which produce most damage and losses as well which occurred most often. It was also possible to analyse derailments that had multi causes. Separate analysis was conducted for derailments on main lines, in shunting yards and in depots – the reason being that these types of derailments differ in nature (mainly cost), whilst the consequences and cost of derailments in shunting yards is very low by comparison. Shunting yard derailments are not reported in many countries although the number is usually higher than on main lines.

Analysis of main line general derailment trends and individual country derailment analysis is presented in this Chapter. Shunting yard derailment analysis is presented in Chapter 5.6.

4.1 Derailment trends for Europe, USA and Russia

Table 4.1 gives a breakdown of the number of derailments for 3 areas over the six year period. The number of derailments is generally decreasing over time - see *Figure 4.1*, which may indicate an improvement in maintenance and inspection over the years.

Table 4.1 Trend of derailments per year

Country	2005	2006	2007	2008	2009	2010
USA	1626	1566	1411	1262	1144	933
Russia	53	59	85	56	55	50
Europe – DNV (ERA)	16	39	32	31	21	18

If the number of derailments is analysed taking into account the volume of transported cargo then results could reflect a decrease in derailments as cargo volume increases. If, however cargo volume also decreases proportionately, then the decrease in derailments may not be as significant and may not be directly related to any technological and operational improvements. In order to compare the data

from the different regions, the analysis presented in table 4.2 below includes a comparison of the number of derailments per billion tonne-km.

Russia, the USA and Europe have many other differences in terms of wagon and bogie technology, axle loads, running conditions and infrastructure, but derailment mechanisms and influencing factors remain the same.

Table 4.2 Volume of transported cargo [million tonne-km]

Country	2005	2006	2007	2008	2009	2010
Russia	1858000	1951000	2090000	2116200	1865300	2011300
USA	2475923	2586807	2583889	2594102	2236647	2334400
Europe	335628	363704	385824	390395	319202	347869

A brief summary of key statistics is given in Table 4.3 –

Table 4.5, including total number of derailments over the six years, and the estimated cost. The exchange rate used for the USA costs is $1.31 = €1, and for UK cost £1 = €1.2.

Table 4.3 Number of freight mainline derailments over six years (2005-2010)

Country	USA	Russia	France	Austria	UK	Germany	UIC	DNV
Number of derailments	11,157	358	30	69	257	84	403	157
Derailment cost	€ 1,113,502,461	€ 14,827,248	€ 20,690,000	€ 42,473,163	€ 43,469,444	€ 61,295,580		
Average cost per derailment	€ 99,803	€ 41,416	€ 689,666	€ 615,553	€ 169,141	€ 729,709		

Table 4.4 Volume of freight transport over six years (2005-2010)

Country	USA	Russia	France	Austria	UK	Germany	UIC
Volume [billion tonne-km]	14811.768	11891.800	226.700	272.095	267.460	653.418	2142.622

Table 4.5 Number of freight mainline derailments over six years (2005-2010) normalised with respect to volume of freight transport

Country	USA	Russia	France	Austria	UK	Germany	UIC
Number of derailments per billion tonne-km	0.753252	0.0301047781	0.132333	0.253588	0.960891	0.128554	0.188087
Derailment cost per billion tonne-km	€ 75,176.88	€ 1,246.85	€ 91,266	€ 156,097	€ 162,527	€ 93,807	
Average cost per derailment per billion tonne-km	€ 6.74	€ 3.48	€ 3,042.20	€ 2262.27	€ 632.40	€ 1,116.76	

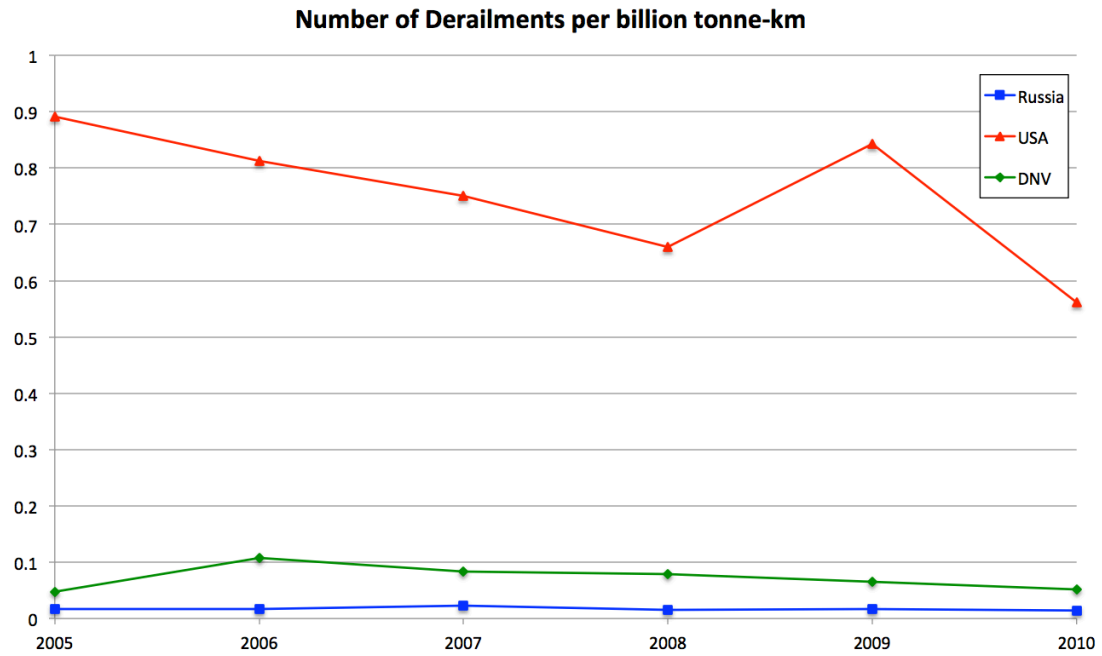


Figure 4.1 Number of derailments per billion tonne-km, for USA, Russia and Europe, over six years (2005-2010)

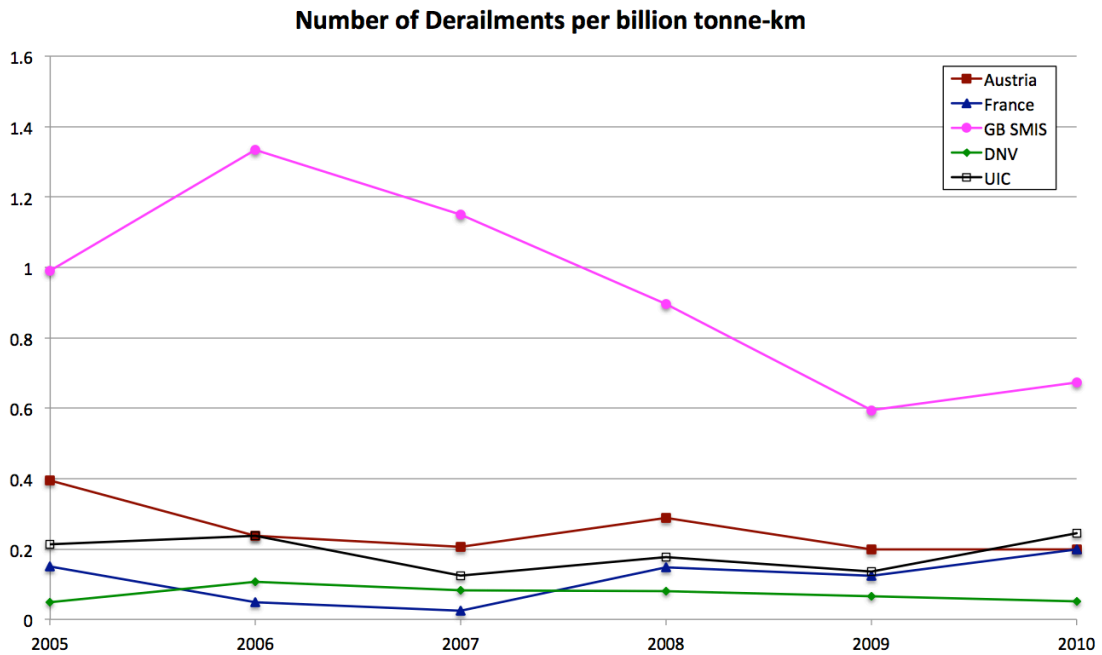


Figure 4.2 Number of derailments per billion tonne-km, for several European countries and UIC, over six years (2005-2010)

4.2 Distribution of derailment causes

4.2.1 Overview and Approach

This section of the report concerns the assessment of the most frequent causes, severity and consequences of derailments and the identification of the most significant areas of work for subsequent WPs to focus on with a view to reducing derailment numbers. This part of the deliverable has the following logic and structure:

1. To re-define the classification derailment causes.
2. The review of a significant number of freight train derailment accidents to establish the causes and consequences of these events.
3. The analysis of safety levels in different regions.
4. Identify comparability of the data from different regions.
5. Understanding the main features of rail freight transportation services in different regions in order to clarify nature of derailment causes.
6. Compare the distribution of causes in the different regions by establishing the percentage contribution from each freight train derailment cause.
7. Identify causes of derailments which have the biggest influence on frequency and severity of consequences of derailments.
8. Calculate the frequency contribution per cause
9. Identify top derailment causes using Pereto's[2] principal.
10. Identify derailment causes that are dominant in all previous ranking methods

4.2.2 Classification of derailment causes

The classification scheme for derailment causes, used in the analysis below, is based on that used by DNV, simply because the DNV study has the most comprehensive European data available. This classification structure allows us to compare data from different sources. This system includes three main categories of derailments:

1. Derailments caused by *Infrastructure* failures
2. Derailments caused by *Rolling Stock* failures
3. Derailments caused by *Operation* failures

Changes to the DNV classification system:

- The DNV classification includes an 'Environment' category. In the analysis below, this has been re-labelled *Weather, Environment and 3rd Party*.
- A large number of derailments have an unknown cause, either wholly or partly. In the DNV classification system there were three 'Unspecified' categories under *Infrastructure*, *Rolling Stock* and *Operations*. As all three categories already have a general 'Other' sub-category,

[2] The Pareto distribution, named after the Italian economist Vilfredo Pareto, is a power law probability distribution tool.

'Unspecified' sub-categories has been removed and replaced by a single main category *Unspecified*.

- A new 'human factors' sub-category has been added to the *Operations* category.
- Sub-categories described as 'other' have been renamed according to context.

Derailments caused by ***Infrastructure*** failures and defects are classified as follows:

1. **Failed substructure**, comprising:
    a. Subsidence
    b. Earth slide / tunnel collapse (leading to derailment, not collision)
    c. Substructure wash-out due to flooding etc
    d. Bridge failure (leading to derailment)
2. **Structural failure of the track superstructure**, comprising:
    a. Rail failures
    b. Joint bar & plug rail failures
    c. Switch component structural failure
    d. Failure of rail support and fastening
    e. Track superstructure unsupported by substructure
    f. Other track and superstructure failure
3. **Track geometry failure**, comprising:
    a. Excessive track twist
    b. Track height/cant failure
    c. Lateral track failure
    d. Track buckles (heat-curves)
    e. Excessive track width
    f. Other or unspecified track geometry causes
4. **Other infrastructure failures**

Derailments caused by ***Rolling Stock*** failures and defects are classified as follows:

1. **Wheelset failures (wheels and axles)**, comprising:
    a. Axle ruptures:
        i. Hot axle box and axle journal rupture
        ii. Axle shaft rupture
        iii. Axle rupture, location not known
    b. Wheel failure:
        i. Rupture of monoblock wheel
        ii. Failure of composite wheel with rim and tyre
        iii. Excessive flange or wheel tread wear (wrong wheel profile)
2. **Bogie and suspension failures**, comprising:
    a. Failure of bogie structure and supports
    b. Spring & suspension failure
    c. Other
3. **Twisted or broken wagon structure/frame**
4. **Wagon with too high twist stiffness in relation to length**
5. **Brake component failure**
6. **Other or unknown rolling stock derailment cause**

Derailments caused by ***Operation*** failures and defects are classified as follows:

1. **Train composition failures**, comprising:
    a. Unfavourable train composition (empties before loaded wagons)
    b. Other
2. **Improper loading of wagon**, comprising:
    a. Overloading
    b. Skew loading
        i. Wagon wrongly loaded
        ii. Wagon partly unloaded
    c. Insufficient fastening of load
    d. Other incorrect loading
3. **Train check and brake testing**, comprising:
    a. Un-suitable brake performance for route characteristics
    b. Brakes not properly checked or tested
    c. Brakes not correct set with respect to load or speed of brake application
4. **Wrong setting of points/turnouts**, comprising:
    a. Wrong setting in relation to movement authority
    b. Point switched to new position while point is occupied by train
5. **Mishandling of train en route**, comprising:
    a. Speeding:
        i. Excessive speed through turnout in deviated position
        ii. Excessive speed elsewhere
    b. Other mishandling of train
6. **Brake shoe or other object left under train**
7. **Human factors**
8. **Other operational failures**

4.2.3 Assessment of data comparability

Collected data shows that the number of derailments in observed regions is different, also after the normalisation per billion ton km. The reason is that each country has its own specific differences in: operating conditions, type of rolling stock, infrastructure, renewal and maintenance policies. This raises a question of comparability of results.

To address this question, we compared the distribution of causes in the sets of data and explained the reasons behind the differences. For the purposes of our analysis we can assume that the statistics on causes in all regions remain comparable.

Aside from the “technical” differences of the regions, important aspects for comparability are:

- Inclusion criteria for the incidents or derailments and
- Quality of causal research after derailment.

4.3 Breakdown and Ranking of Derailment Causes

The Number of derailments (as a share of the total) is the number of derailments in a particular category divided by the total number of derailments across all categories, expressed as a percentage. For example, in the dataset used by DNV, there are 157 derailments in total for the years 2005-2010. In the category *Rolling Stock* there are 60 derailments, so the number of derailments (as share of total) is 38.22%.

Figure 4.3 and
Table *4.6* show the breakdown of the number of derailments (as share of total) into major categories, i.e., *Infrastructure*, *Rolling Stock* and *Operations*, separating out *Weather, Environment & 3rd Party* and *Unspecified*. Initially comparisons between regions (USA, Russia, EU) were made because of similarities in length of track, volume of transported cargo, etc. Further comparisons of derailment causes in European countries were made to show how cause trends differ from country to country resulting from accuracy of data available, country specifics and size of the sample. For this purpose, three country data sets are used: Austria, France and GB. Additionally, the average of the three is included together with those from the DNV and UIC data sets.

Figure 4.3 shows that infrastructure is a major cause of derailments in the USA, and rolling stock the predominant cause in Russia Three major categories are clearly responsible for a large share of the derailments in all three regions.

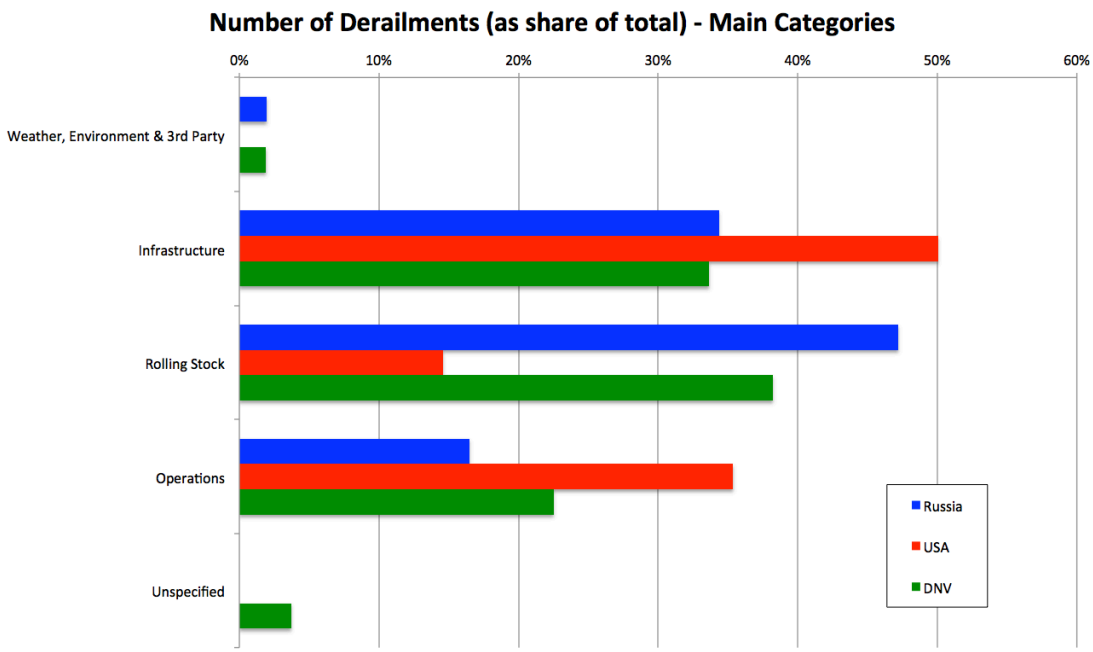


Figure 4.3 Breakdown of number of derailments (as share of total) into major categories, for regions

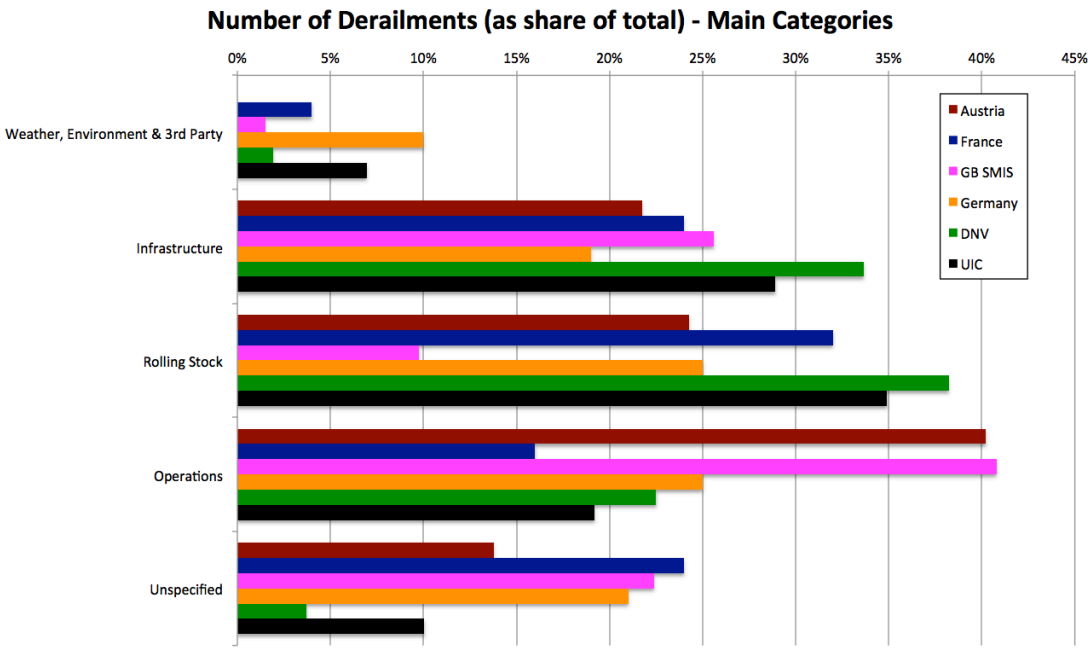


Figure 4.4 Breakdown of number of derailments (as share of total) into major categories, for Europe

From Figure 4.4, depicting European data, for the correlation between data from the European countries and that gathered by DNV and UIC is evident with the major causal influence being rolling stock, followed by infrastructure. Both Austria and GB have Operations as the largest causal category and data from Germany is the most evenly spread.

Table 4.6 Breakdown of number of derailments (as share of total) into major categories

Shares by main category:	DNV	Russia	USA	UIC	Austria	France	Germany	GB SMIS
Weather, Environment, 3rd Party	1.91%	1.96%	0.00%	6.95%	0.00%	4.00%	10%	1.49%
Infrastructure	33.65%	34.36%	50.05%	28.91%	21.74%	24.00%	19%	25.59%
Rolling Stock	38.22%	47.21%	14.58%	34.90%	24.28%	32.00%	25%	9.76%
Operations	22.51%	16.48%	35.37%	19.19%	40.22%	16.00%	25%	40.78%
Unspecified	3.72%	0.00%	0.00%	10.05%	13.77%	24.00%	21%	22.37%

It is clear that we have two outliers in our set of data in USA and in Russia. It relates to specific countries conditions. More detailed analysis and explanations of these outliers will be provided during detailed analysis of these categories.

In subsequent sections Figure 4.5 and Figure 4.6 show the further breakdown of the *Infrastructure* category, Figure 4.8 and Figure 4.9 show the breakdown of the *Rolling Stock* category, and Figure 4.11 shows the breakdown of the *Operations* category. (See Figure A3.1 for a breakdown across all categories.)

The UIC data set has not been translated into the sub-categories used here, and is not included in these figures.

4.3.1 Infrastructure

The main Infrastructure category failures (*Figure 4.5*) leading to freight train derailments in Europe are:

1. Track geometry failure
2. Structural failure of the track superstructure.

As a result of the data in the various databases not being classified in the same way it was difficult to allocate all causes of derailments to the DNV format. As a result some causes were classified as 'other infrastructure' leading to an increase in this category. In order to mitigate the influence of causes in the category 'other' on final results and not to miss important causes for future work, investigation reports of these derailments will be provided.

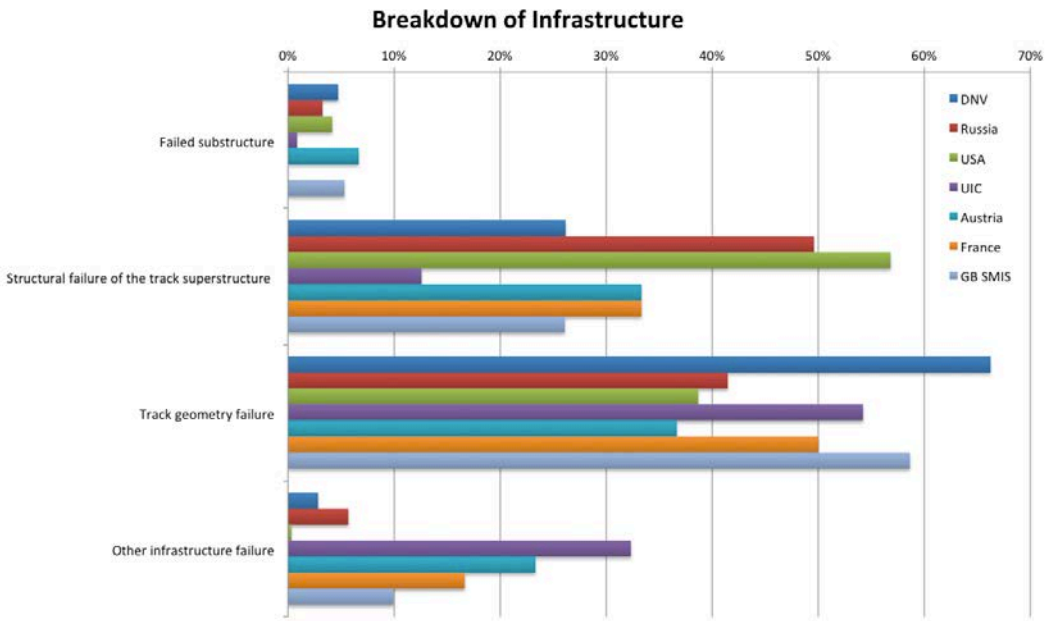


Figure 4.5 Infrastructure main causes categories leading to freight train derailments

Track geometry is much more dominant in Europe as a whole (UIC and DNV) and other presented European countries, compared with the USA and Russia, where the track superstructure number of causes is higher.

For smaller Infrastructure sub-categories please see *Figure 4.6*.

For the USA, which as noted above is dominated by *Infrastructure* causes, the main *Infrastructure* sub-categories are: rail failures, excessive track width, switch component structural failure and excessive track twist.

<u>USA - Infrastructure derailments specifics</u>
As can be seen in *Figure 4.6*, the US experiences significantly higher rates of rail related derailments than Europe or Russia. This is primarily because of the significantly higher axle loads in operation (33 tonnes) combined with very heavy unit train operations (12,000+ tonne trains) resulting in a significantly

higher level of rail loading. The result is higher rail contact stresses and associated contact stress related problems such as rolling contact fatigue, rail spalling, rail shelling and the development of such internal rail defects as Detailed Fracture (from Shell), Vertical Split Head, Horizontal Split head, etc. The fracture of these defects under traffic represents a significant portion of the broken rail derailments reported in the US.

Europe - Infrastructure derailments specifics

Based on the number of derailments (as share of total), averaged over the country data sets, the top Infrastructure sub-categories for Europe, see Figure 4.7, are:

1. excessive track width
2. track height / cant failure
3. rail failures
4. excessive track twist
5. track superstructure unsupported by substructure
6. switch component structural failure

Care is required for analysis of data from individual countries due to small sample sizes. Each country has its own localized conditions which are not reflected when looking at Europe as a whole.

Russia – Infrastructure derailments specifics

In Russia excessive track width is the primary infrastructure cause, but this is usual in other countries. Failure of rail support and rail fastening however is unusually high in this region.

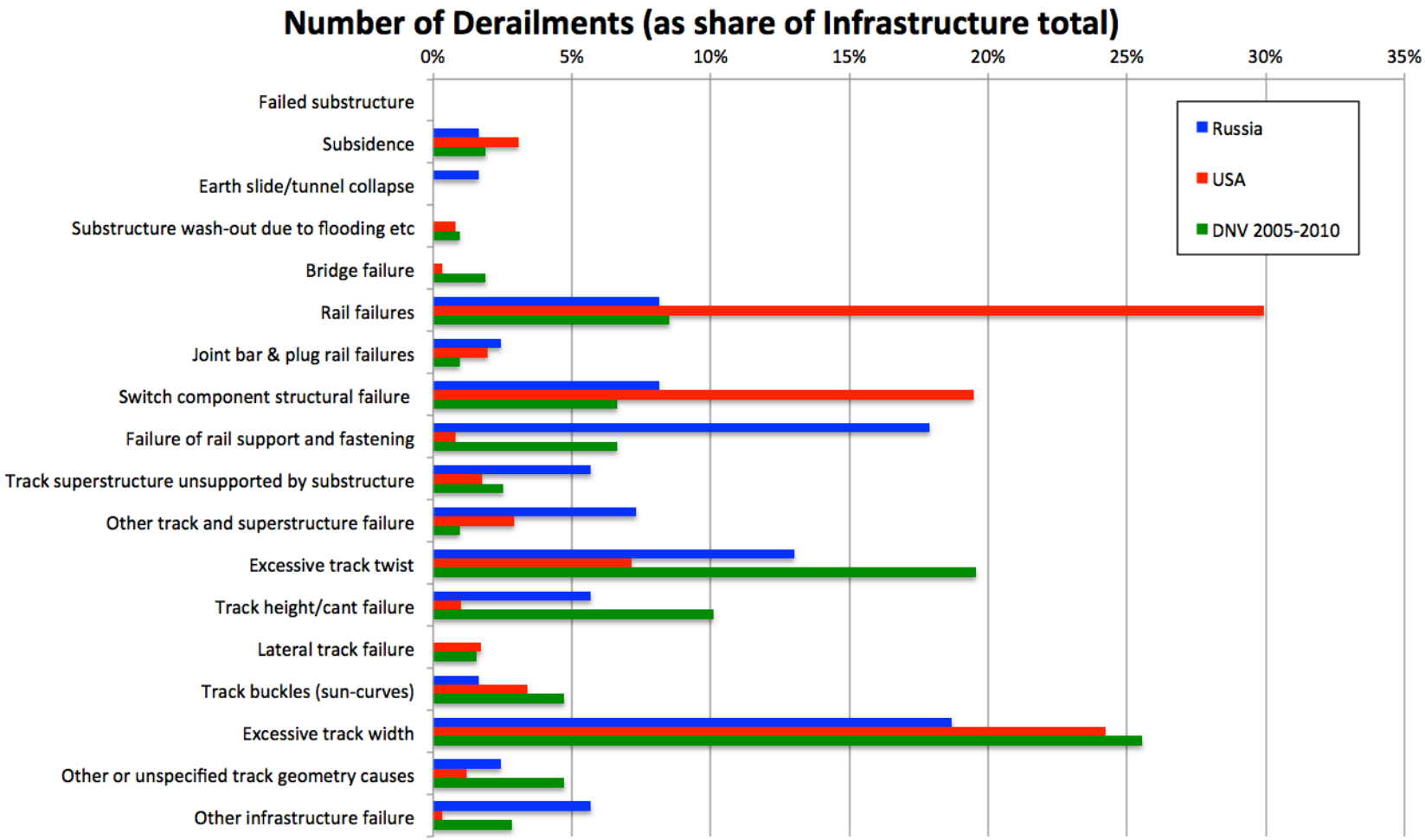


Figure 4.6 Breakdown of number of derailments (as share of total) in Infrastructure category into sub-categories, for regions

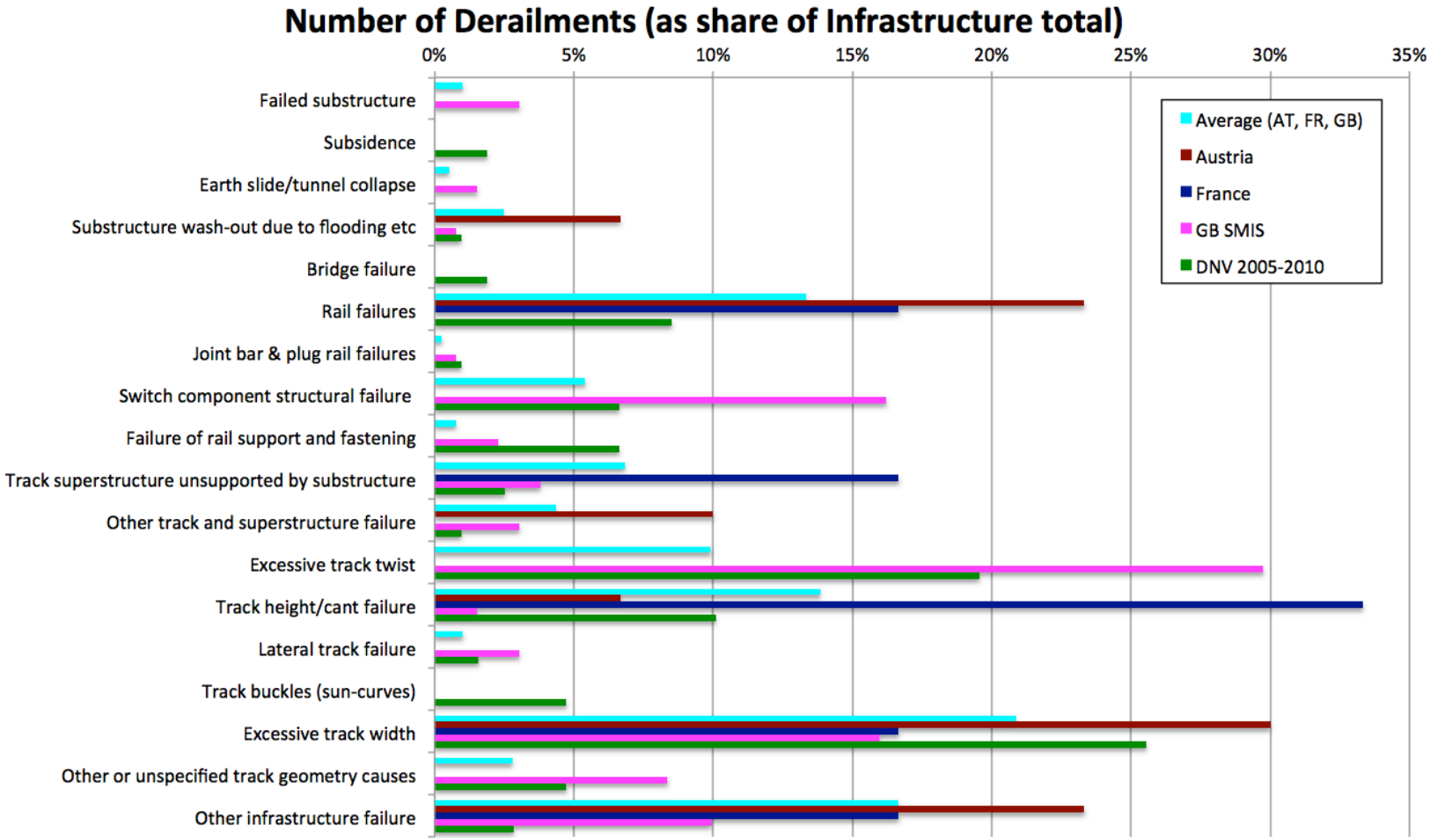


Figure 4.7 Breakdown of number of derailments (as share of total) in Infrastructure category into sub-categories, for Europe

4.3.2 Rolling stock

The Rolling stock main category failures leading to freight train derailments (see *Figure 4.8*), for Europe, USA and Russia are:

1. Wheels and axles failure
2. Bogie and suspension failure

As a result of the need to transfer data into the DNV format many categories within 'Rolling Stock' were classified as 'other.' As in the case of infrastructure failures, in order to mitigate any influence of causes in the category 'Others' on final results and not to miss important causes for future work, investigation reports will be provided of these derailments.

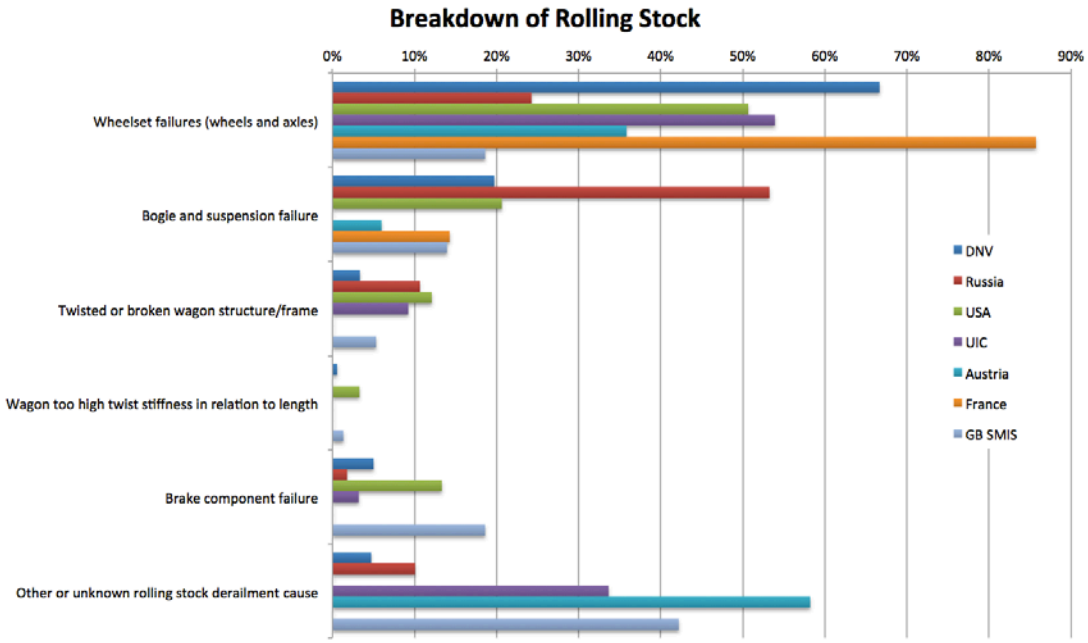


Figure 4.8 Rolling stock main causes categories leading to freight train derailments

The Rolling Stock sub-categories (see *Figure 4.9*) are not as easy to rank, due partly to the axle failure and wheel failure sub-categories being split into further sub-categories. In addition, there is considerable variation between data sets, and there are a large number of derailments in the 'other or unknown' sub-category.

Based on the number of derailments (as share of total), averaged over the country data sets, and ignoring the large number of 'other or unknown', the top five Rolling Stock sub-categories for Europe are:

1. hot axle box and axle journal rupture
2. wheel brake and failure
3. spring and suspension failure
4. axle brake and failure
5. brake failure

Hot axle box and axle journal rupture is the highest category in Europe, due to bearing failure. Bearings are mainly monitored by Hot Axle Box Detector's (HABD). The failure of composite wheels can be caused by poor tyre connection, tyre rupture or by incorrect fitting. Composite wheels are generally being phased out and replaced by solid wheels.

Solid wheel ruptures occur as a result of braking effects, unexpected loads (greater than design loads) or the metallurgical properties of steel (old wheels). Rupture of solid wheels is directly linked to wheel technology (cast wheels in North America and forged and laminated wheels in Europe).
The incorrect tread profile is one of the multiple causes contributing to derailments.

Axle shaft rupture: the number of shaft ruptures, for reasons other than axle box failure, has decreased significantly over the last 10 years and is no longer a problem in Europe. Axle shaft ruptures are mainly due to poor maintenance, mechanical or corrosion damage on the surface not treated during maintenance activities.

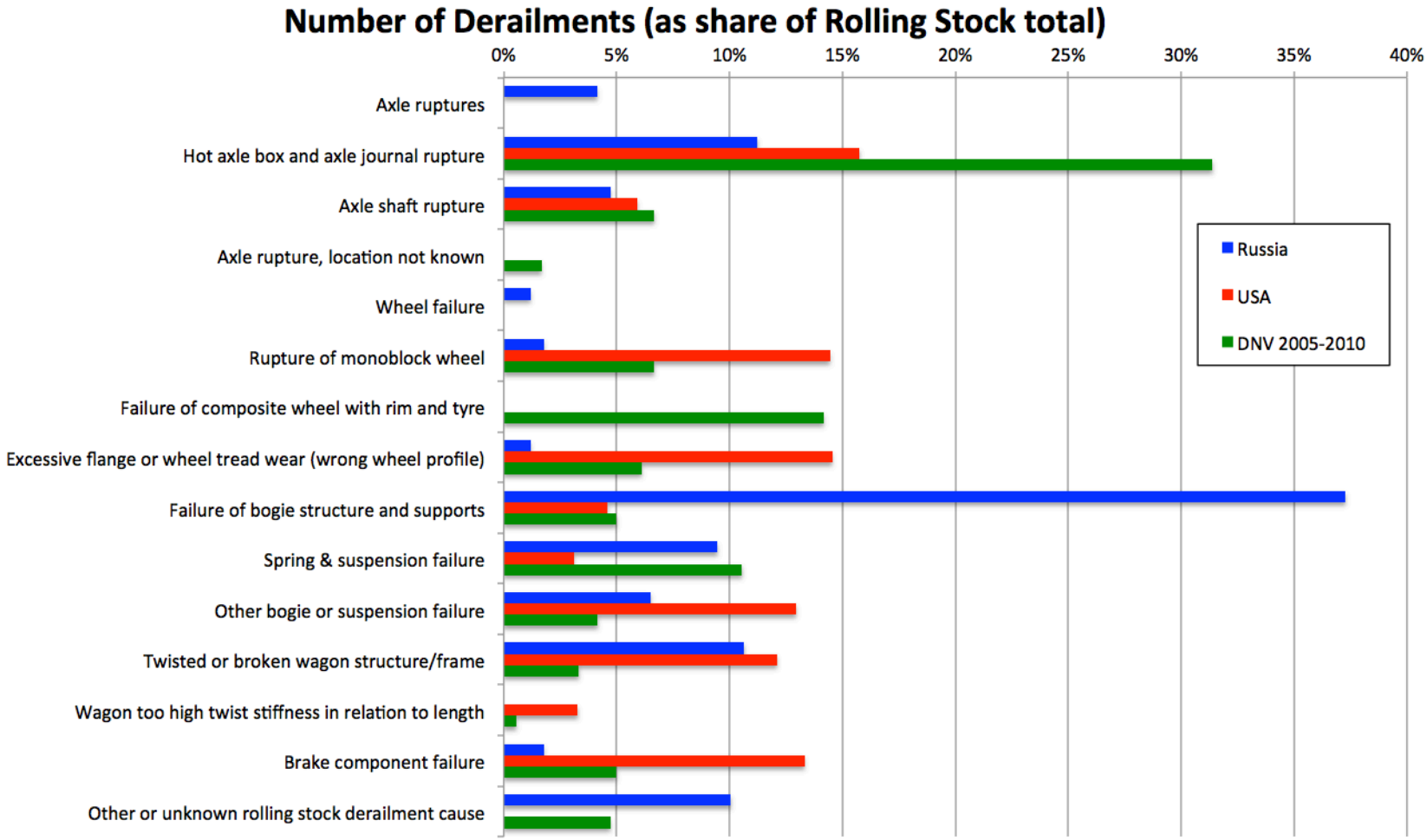


Figure 4.9 Breakdown of number of derailments (as share of total) in Rolling Stock category into sub-categories, for world regions

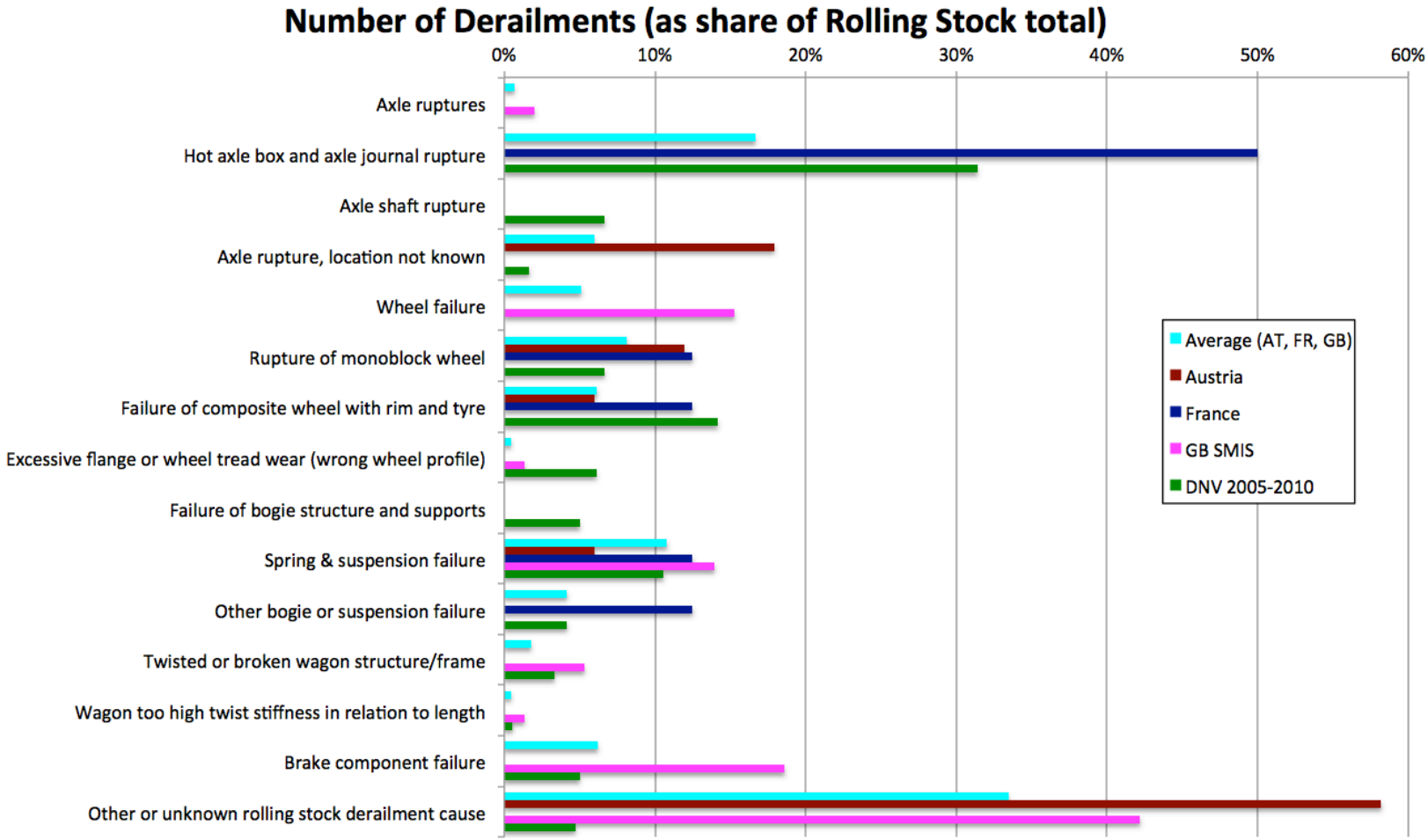


Figure 4.10 Breakdown of number of derailments (as share of total) in Rolling Stock category into sub-categories, for Europe

Failure of bogie structure, see *Figure 4.9*, is the highest problem for Russian rolling stock. One reason is that new suppliers and plants producing bogies (cast bogies) have problems with casting technology. Now this question is solving through the new regulations.

Compared to mainland Europe, Great Britain has had a smaller proportion of bearing and axle failures, which can be attributed to wagon fleet age, specific wagons for traffic and the maintenance regime which suits the axle design.

GB have had a higher percentage of derailments as a result of brake failings, the majority of which have been due to handbrakes left applied to wagons when moving on the mainline. 100% of GB wagons currently have handbrakes and investigative work is progressing to ascertain if the risks, as a result of having a handbrakes, outweigh the option of having other operational means for securing wagons in yards (especially with the preponderance of train load traffic).

The main rolling stock derailment cause in France is bearing damage (category hot axle box and axle journal rupture). In France and in Europe, bearings are mainly monitored by HABD.

4.3.3 Operation

The Operations category is dominated by 'human factors,' see *Figure 4.11*, which is a broad sub-category with many possible additional sub-categories (see, e.g., the UIC categorisation table). Not all data sets use the human factors sub-category (it was not in the original DNV categorisation), and there is some ambiguity between human factors and some of the other operation sub-categories. It is recommended that the human factor category be studied separately.

Based on the number of derailments (as share of total), averaged over the country data sets, the top five Operations sub-categories for Europe are:

1. human factors
2. wagon wrongly loaded
3. point switched to wrong position
4. other mishandling of train including driver caused SPAD
5. brake shoe or other object left under train

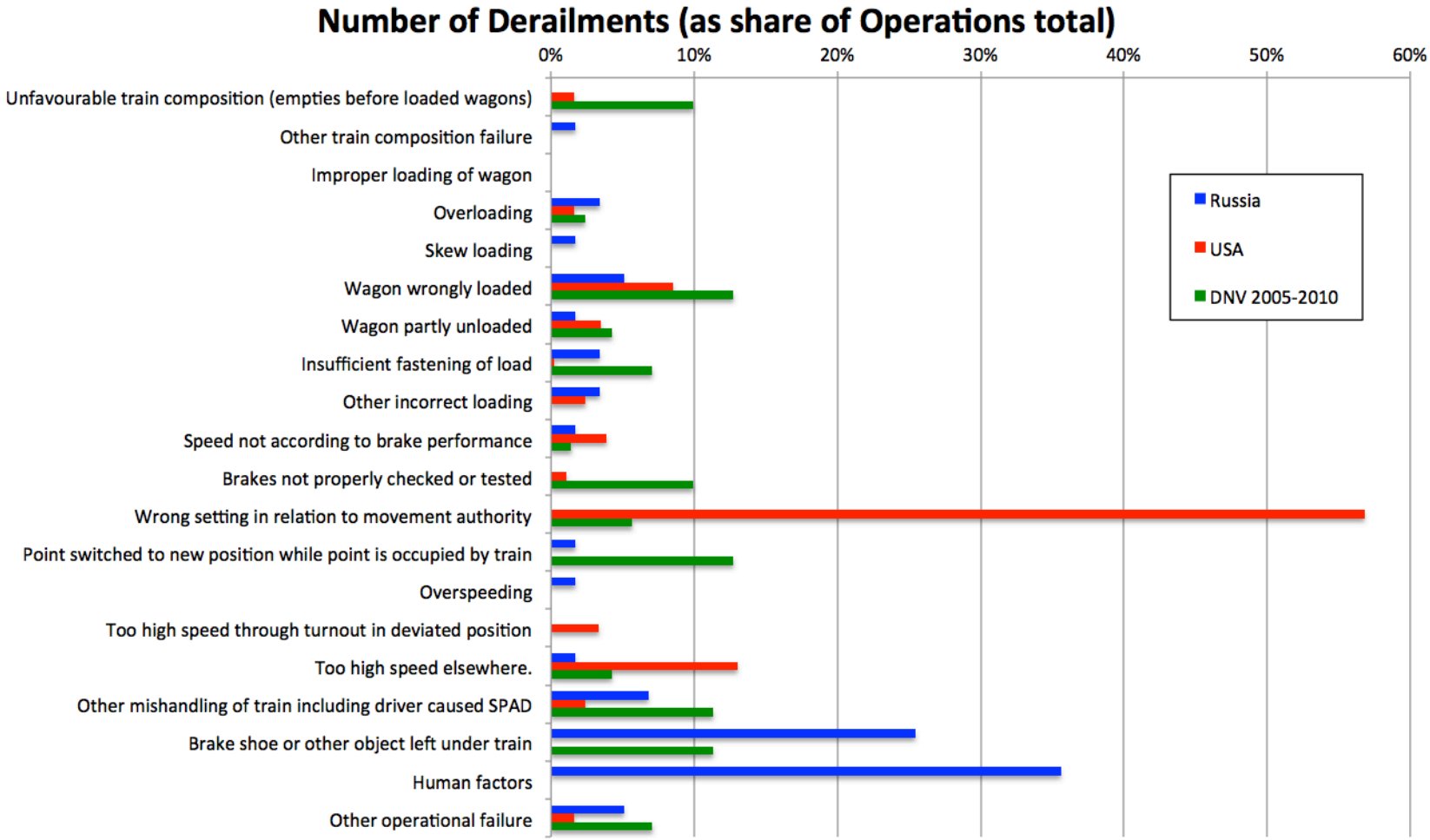


Figure 4.11 Breakdown of number of derailments (as share of total) in Operations category into sub-categories, for world regions

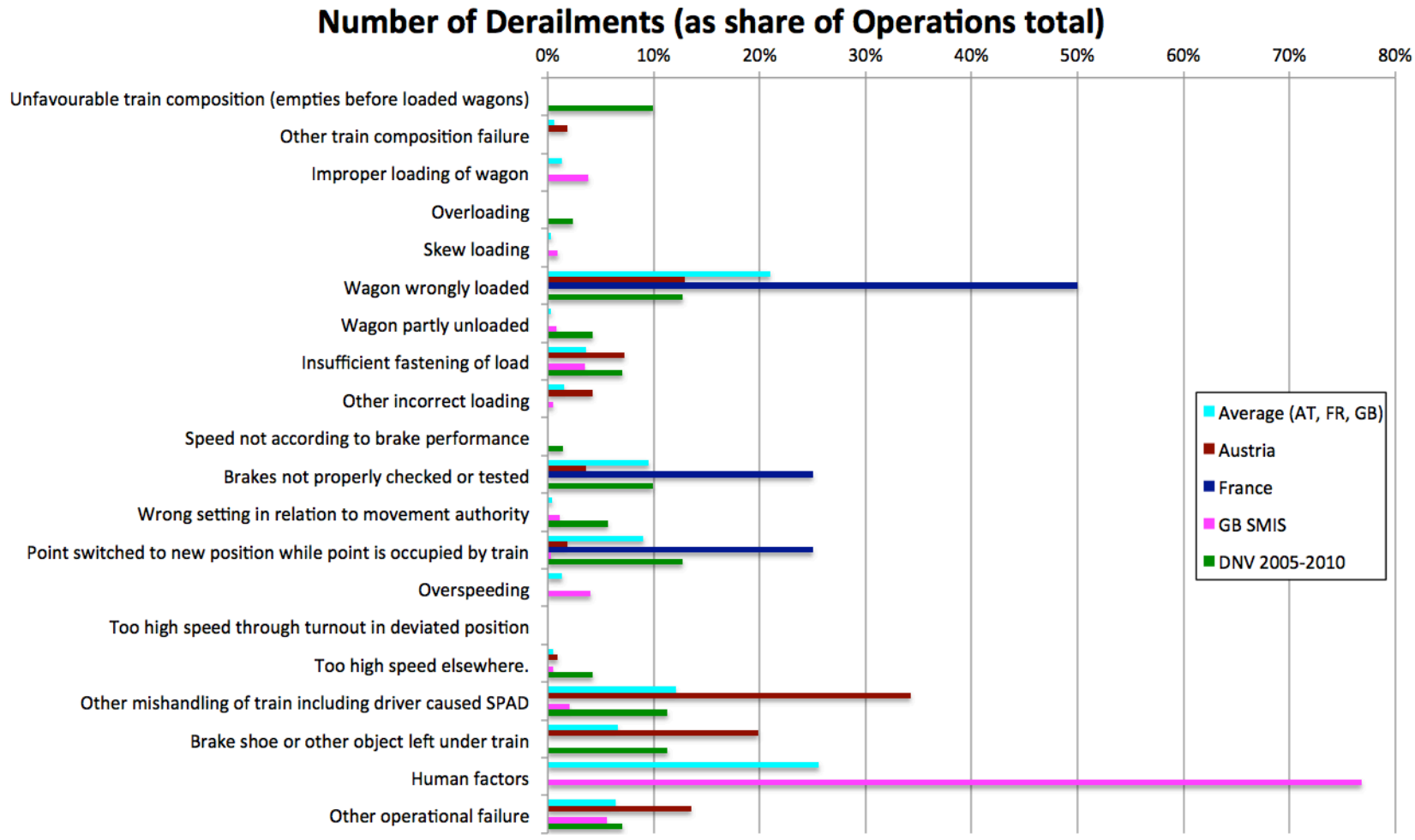


Figure 4.12 Breakdown of number of derailments (as share of total) in Operations category into sub-categories, for Europe

The GB data shows that over the five year period from 2005 to 2010 the number of derailment incidents has significantly fallen with the annual number of incidents dropping from 113 incidents in 2001 to 33 in 2011. It should be noted that over the period from 2005 to 2010 in just over 20% of all derailments, the cause has not been established. Despite this the main contributor to derailments resulting from operational failures relate to a human error with just approximately 80% being attributed to this sub-category.

The RAIB has conducted 17 investigations into freight train derailments since 2005. Of the 17 investigations, operations had a part to play in 10 of the derailments although rarely as the primary cause.

The analysis of data regarding Yards and Sidings is incomplete due to UK Railway Group Standards not applying to these locations (as a result provision of information about accident and incidents in these areas to SMIS is not mandatory). It is only recently that reports of derailments within yards and sidings have been entered into the SMIS database on a regular basis. The dataset is therefore incomplete and a true picture cannot be determined. Despite this, when analysing the dataset available, a similar picture is seen in relation to the proportion of derailments caused by human error.

A rising trend of rolling stock related derailments in GB is due to asymmetric loading. This is almost always due to poorly loaded containers and work is progressing to better understand this problem.

In France unbalanced mainline loading, due to incorrect settings by the loader, is the most dominant operational cause. The second one is point switched to new position, which is also regarded as human error.

4.4 Ranking by number of derailments

In *Figure 4.13* and *Figure 4.14*, the bars represent the number of derailments in a particular category for a particular country or region divided by the total number of derailments across all categories for that country, expressed as a percentage. All categories and subcategories have been included in the ranking, including Weather, Environment & 3rd Party and Unspecified.
Figure 4.13 gives the top 20 categories (i.e., derailment causes) ranked according to the average value in each category, calculated as the average of the percentages for Russia, the USA and the DNV / ERA. (The average is not plotted.)

Figure 4.14 gives the top 20 categories ranked according to the average value in each category, calculated as the average of the percentages for Austria, France and GB. (The average is not plotted.) DNV / ERA is included for comparison.

Unspecified is ranked first, while Weather, Environment & 3rd Party is sixteenth. ‘Human factor’ is ranked second with a very high value specific to the GB dataset.

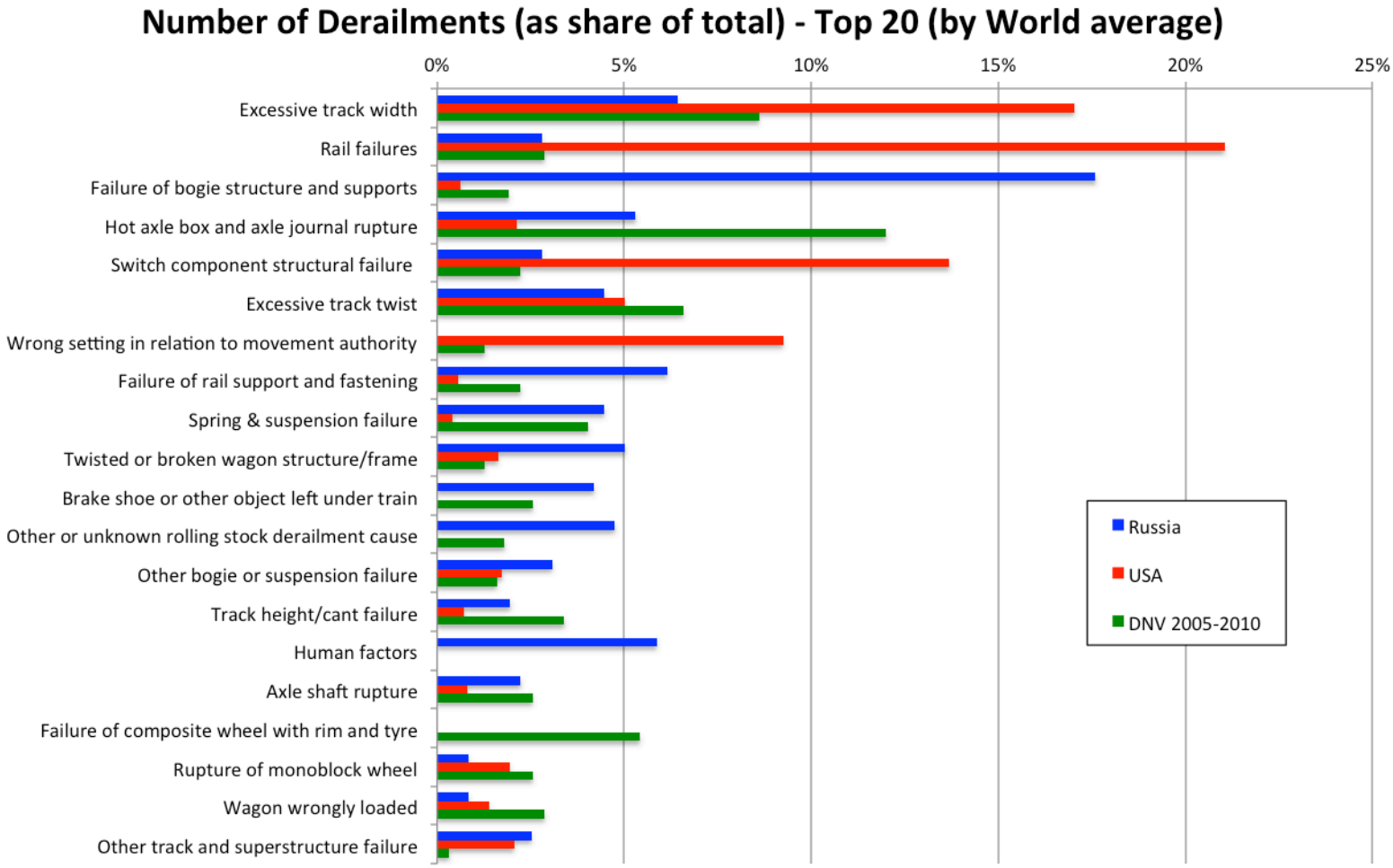


Figure 4.13 Number of derailments (as share of total): Top 20 sub-categories, based on the average value across the data sets in each sub-category, for world regions

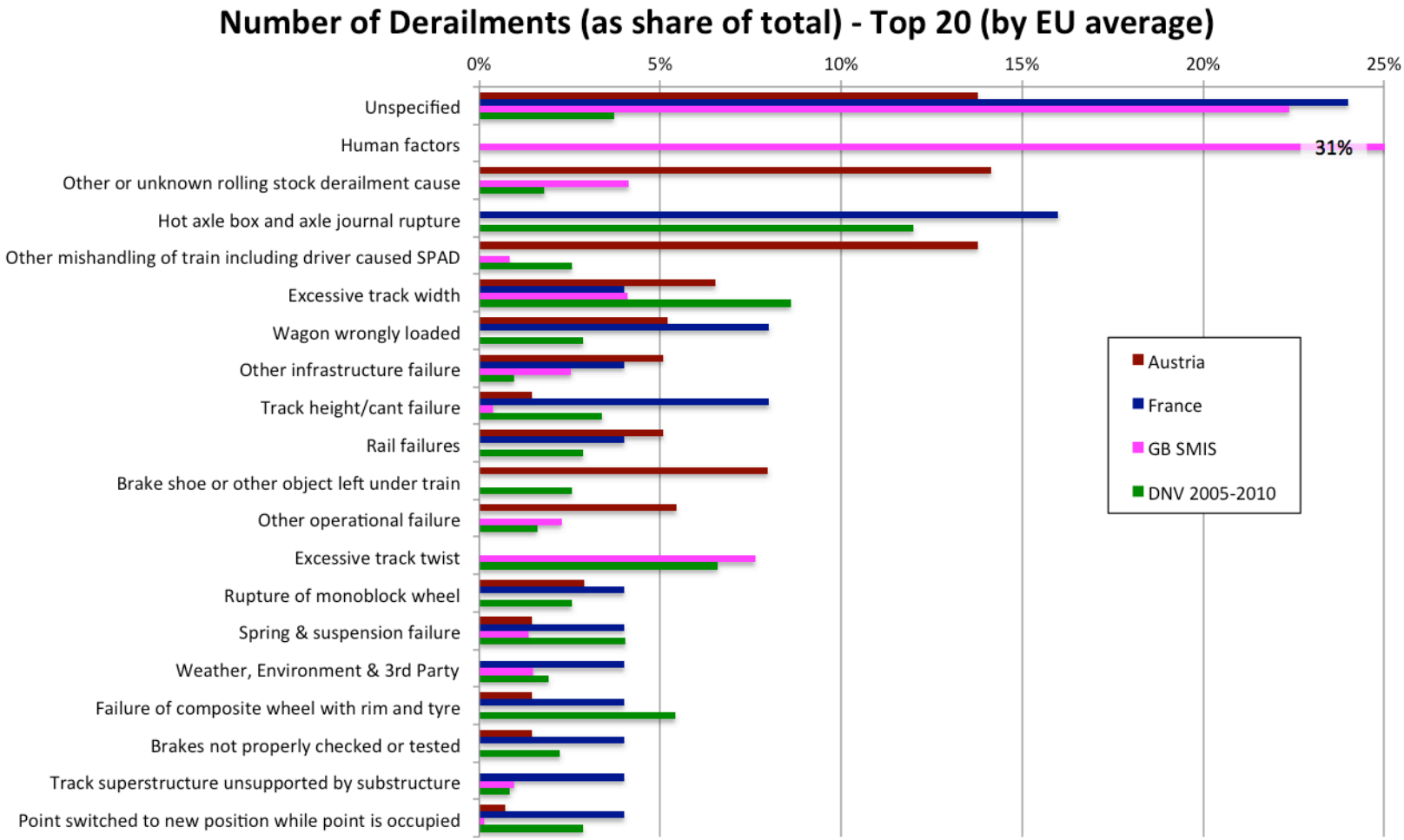


Figure 4.14 Number of derailments (as share of total): Top 20 sub-categories, based on the average value across the data sets in each sub-category, for Europe

Not including 'Human factors,' or 'Unspecified' or any sub-categories marked 'other', and based on the average number of derailments (as share of total) in each category or sub-category, derailment causes for Europe can be ranked as:

1. [RS] hot axle box and axle journal rupture
2. [I] excessive track width
3. [O] wagon wrongly loaded
4. [I] track height / cant failure
5. [I] rail failures
6. [O] brake shoe or other object left under train
7. [I] excessive track twist
8. [RS] rupture of monoblock wheel
9. [RS] spring and suspension failure
10. [RS] failure of composite wheel with rim and tyre
11. [O] brakes not properly checked or tested
12. [I] track superstructure unsupported by substructure
13. [O] point switched to new position while point is occupied

4.4.1 Final ranking of European mainline derailment causes

To create a **final ranking** based on numbers of derailments, **third-level categories have been merged** with the second level, so rather than the four categories, wheel failure, rupture of monoblock wheel, failure of composite wheel with rim and tyre, and excessive flange or wheel tread wear (wrong wheel profile), there is a single wheel failure category. Similarly for axle ruptures, skew loading and excessive speeding.

Ranking according to the DNV / ERA data set has been compared to the ranking against the average across Austria, France and GB, and a final ranking based on the average of these is presented in Table 4.7. If ambiguous causes such as Unspecified or those labelled with 'other' are ignored, then the top 8 causes are:

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

Table 4.7 Derailment causes, where third-level categories are merged. Comparison of rankings based on numbers of derailments (as share of total) for EU (Average) and DNV, where 1 is the highest rank, and a final ranking based on the average of these.

Derailment Cause Category	EU (Average)	DNV	Average
Axle ruptures	**3**	**1**	2
Unspecified	**1**	**7**	4
Excessive track width	**6**	**3**	4.5
Wheel failure	**7**	**2**	4.5
Skew loading	**8**	**6**	7
Other mishandling of train including driver caused SPAD	**5**	**11**	8
Excessive track twist	**14**	**4**	9
Track height/cant failure	**10**	**8**	9
Rail failures	**11**	**9**	10
Spring & suspension failure	**15**	**5**	10
Brake shoe or other object left under train	12	12	12
Other or unknown rolling stock derailment cause	**4**	**20**	12
Point switched to new position while point is occupied by train	**19**	**10**	14.5
Brakes not properly checked or tested	17	16	16.5
Weather, Environment & 3rd Party	16	17	16.5
Switch component structural failure	21	13	17
Other infrastructure failure	**9**	**28**	18.5
Other operational failure	13	25	19
Insufficient fastening of load	20	24	22
Other bogie or suspension failure	22	23	22.5
Brake component failure	27	19	23
Failure of rail support and fastening	33	14	23.5
Human factors	**2**	**45**	23.5
Other or unspecified track geometry causes	25	22	23.5
Track superstructure unsupported by substructure	18	30	24
Overspeeding	24	29	26.5
Unfavourable train composition (empties before loaded wagons)	43	15	29
Failure of bogie structure and supports	42	18	30
Other track and superstructure failure	23	37	30
Twisted or broken wagon structure/frame	34	26	30
Track buckles (sun-curves)	41	21	31
Wrong setting in relation to movement authority	35	27	31
Substructure wash-out due to flooding etc	28	35	31.5
Lateral track failure	31	33	32
Failed substructure	30	40	35
Other incorrect loading	26	44	35
Subsidence	39	31	35
Bridge failure	40	32	36
Improper loading of wagon	29	43	36
Joint bar & plug rail failures	37	36	36.5
Other train composition failure	32	42	37
Earth slide/tunnel collapse	36	41	38.5
Wagon too high twist stiffness in relation to length	38	39	38.5
Overloading	44	34	39
Speed not according to brake performance	45	38	41.5

4.5 Alternative approaches to ranking

4.5.1 Number of Derailments per billion tonne-km

Number of Derailments per billion tonne-km is an alternative method for comparing the number of derailments across different countries. This scales the number of derailments by the standard measure of transported cargo: the tonne-km represents 1 tonne of cargo transported 1 kilometre. For the USA, the equivalent is the ton-mile, which has been converted here to tonne-km. (For the DNV data set, the annual tonne-km have been determined from EUROSTAT).

Figure 4.15 and *Figure 4.16* present the Top 20 based on the number of derailments per billion tonne-km. In Figure 4.15 the ranking is according to the average value across Russia, the USA and DNV / ERA. In *Figure 4.16*, the ranking is according to the average across Austria, France and GB. It is clear by this method that the USA dominates the World ranking, and GB dominates the EU ranking.

See Appendix 1 Figure A1.2 for a breakdown across all categories.

Table 4.8 gives the ranking according to the EU average of number of derailments per billion tonne-km.

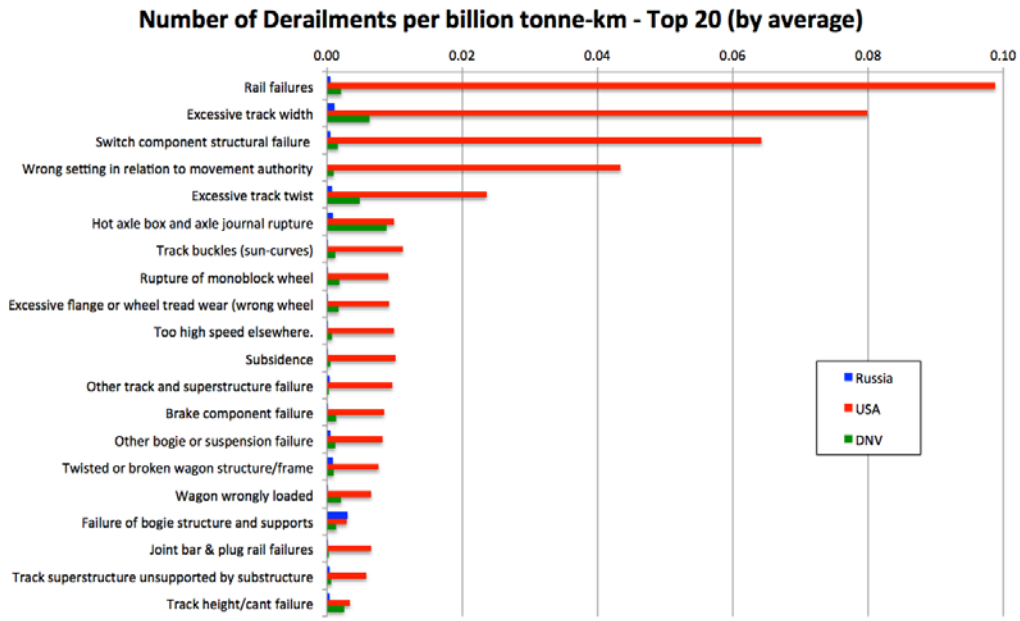


Figure 4.15 Number of derailments per billion tonne-km: Top 20 sub-categories, based on the average value across Russia, the USA and DNV / ERA in each sub-category.

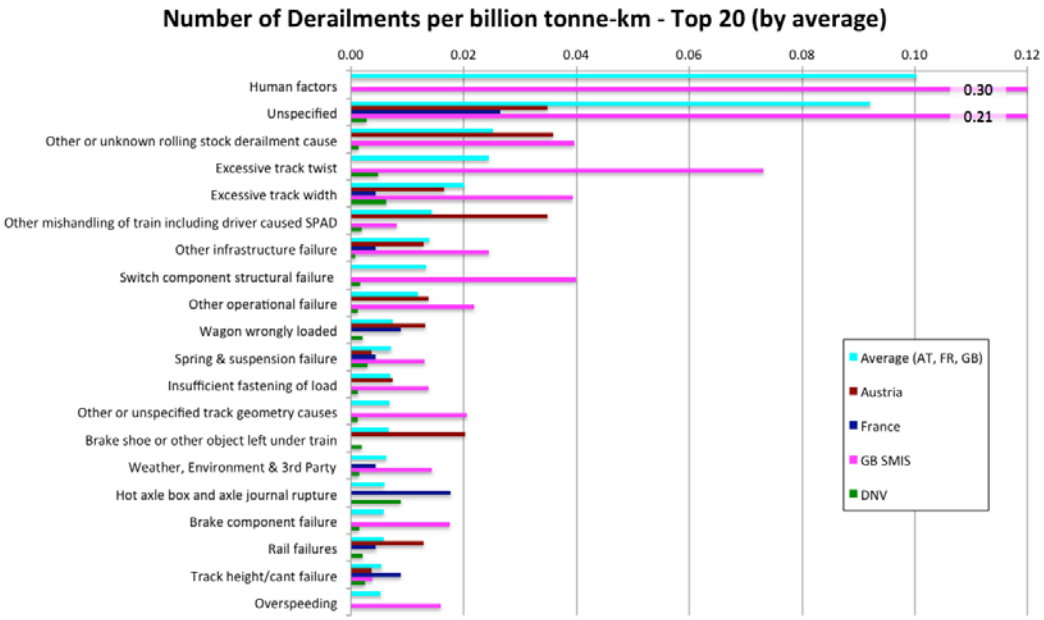


Figure 4.16 Number of derailments per billion tonne-km: Top 20 sub-categories, based on the average value across Austria, France and GB in each sub-category.

Cost of Derailments (as share of total) provides a way to determine the relative impact of different types of derailment based on the estimated costs of individual derailments. The costs are often difficult to estimate and calculation methods will be different in different countries, so here the cost for each category or sub-category is divided by the total cost for each country. Of the data sets used in this study, only Russia, the USA and Austria have costs associated with individual derailments.

Top 20 ranking according to the average across the data sets is presented in *Figure 4.17*.

See Figure A3.3 for a breakdown across all categories. *Table 4.9* gives the ranking of causes.

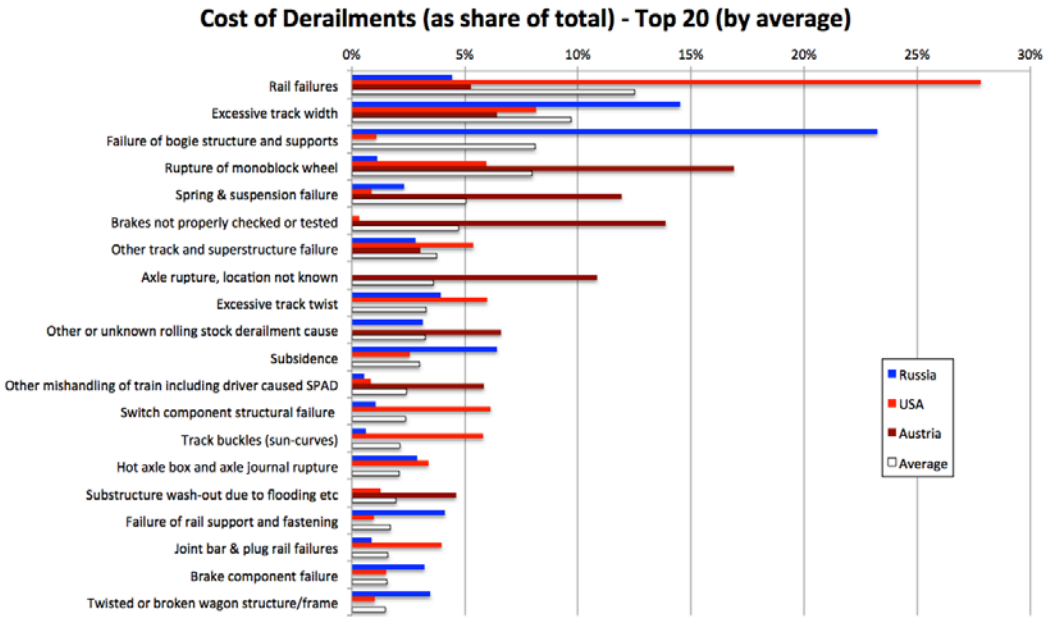


Figure 4.17 Cost of derailments (as share of total): Top 20 sub-categories, based on the average value across the data sets in each sub-category.

Table 4.8 Ranking of causes with third-level causes merged, according to the average number of derailments per billion tonne-km across Austria, France and GB.

(EU Average)	Causes
0.100326	Human factors
0.092122	Unspecified
0.025134	Other or unknown rolling stock derailment cause
0.024386	Excessive track twist
0.020069	Excessive track width
0.014338	Other mishandling of train including driver caused SPAD
0.013901	Other infrastructure failure
0.013294	Switch component structural failure
0.011864	Other operational failure
0.011809	Wheel failure
0.010180	Axle ruptures
0.009657	Skew loading
0.007057	Spring & suspension failure
0.007020	Insufficient fastening of load
0.006855	Other or unspecified track geometry causes
0.006738	Brake shoe or other object left under train
0.006248	Weather, Environment & 3rd Party
0.006226	Overspeeding
0.005816	Brake component failure
0.005758	Rail failures
0.005412	Track height/cant failure
0.005027	Improper loading of wagon
0.004586	Track superstructure unsupported by substructure
0.004330	Other track and superstructure failure
0.002695	Brakes not properly checked or tested
0.002498	Point switched to new position while point is occupied by train
0.002493	Failed substructure
0.002493	Lateral track failure
0.002052	Other incorrect loading
0.001869	Failure of rail support and fastening
0.001848	Substructure wash-out due to flooding etc
0.001662	Twisted or broken wagon structure/frame
0.001470	Other bogie or suspension failure
0.001454	Wrong setting in relation to movement authority
0.001246	Earth slide/tunnel collapse
0.000623	Joint bar & plug rail failures
0.000613	Other train composition failure
0.000415	Wagon too high twist stiffness in relation to length
0.000000	Subsidence
0.000000	Bridge failure
0.000000	Track buckles (sun-curves)
0.000000	Failure of bogie structure and supports
0.000000	Unfavourable train composition (empties before loaded wagons)
0.000000	Overloading
0.000000	Speed not according to brake performance

Table 4.9 Ranking of causes according to cost as share of total, averaged across Russia, the USA and Austria.

(Average)	Causes
12.51%	Rail failures
9.69%	Excessive track width
8.62%	Wheel failure
8.10%	Failure of bogie structure and supports
7.64%	Axle ruptures
5.04%	Spring & suspension failure
4.74%	Brakes not properly checked or tested
3.75%	Other track and superstructure failure
3.30%	Excessive track twist
3.25%	Other or unknown rolling stock derailment cause
3.00%	Subsidence
2.41%	Other mishandling of train including driver caused SPAD
2.40%	Switch component structural failure
2.15%	Track buckles (sun-curves)
1.95%	Substructure wash-out due to flooding etc
1.70%	Failure of rail support and fastening
1.61%	Skew loading
1.61%	Joint bar & plug rail failures
1.57%	Brake component failure
1.50%	Twisted or broken wagon structure/frame
1.28%	Weather, Environment & 3rd Party
1.12%	Other operational failure
1.09%	Unspecified
1.03%	Track height/cant failure
0.94%	Other incorrect loading
0.89%	Wrong setting in relation to movement authority
0.86%	Brake shoe or other object left under train
0.85%	Track superstructure unsupported by substructure
0.65%	Other infrastructure failure
0.62%	Overspeeding
0.61%	Insufficient fastening of load
0.60%	Other bogie or suspension failure
0.53%	Lateral track failure
0.48%	Human factors
0.43%	Other or unspecified track geometry causes
0.41%	Other train composition failure
0.28%	Earth slide/tunnel collapse
0.23%	Speed not according to brake performance
0.21%	Bridge failure
0.21%	Overloading
0.07%	Wagon too high twist stiffness in relation to length
0.05%	Unfavourable train composition (empties before loaded wagons)
0.04%	Point switched to new position while point is occupied by train
0.00%	Failed substructure
0.00%	Improper loading of wagon

4.5.2 Frequency ranking of derailment cause categories by Pareto function

The data from all countries were combined and using the principle of Pareto, major causes which lead to 80% of derailments were identified. The number of derailments per billion tonnes kilometres, for each cause, was estimated as a sum of that number from each country. The top causes estimated using the Pareto functions are given in *Table 4.10*.

Table 4.10 Top causes identified using the Pareto function and using values from the D-Rail database

	Total/billion tkm	Percentage as share of total	Pareto Accrued
Human factors	0.301991	16.67%	16.67%
Unspecified	0.276366	15.26%	31.93%
Excessive track width	0.141221	7.80%	39.73%
Rail failures	0.116515	6.43%	46.16%
Switch component structural failure	0.104607	5.77%	51.93%
Excessive track twist	0.097510	5.38%	57.32%
Other or unknown rolling stock derailment cause	0.076222	4.21%	61.52%
Wrong setting in relation to movement authority	0.047743	2.64%	64.16%
Other mishandling of train including driver caused SPAD	0.045040	2.49%	66.65%
Other infrastructure failure	0.043103	2.38%	69.03%
Other operational failure	0.036978	2.04%	71.07%
Wagon wrongly loaded	0.028637	1.58%	72.65%
Hot axle box and axle journal rupture	0.028489	1.57%	74.22%
Brake component failure	0.025985	1.43%	75.65%
Other or unspecified track geometry causes	0.024668	1.36%	77.02%
Spring & suspension failure	0.023894	1.32%	78.34%
Other track and superstructure failure	0.023058	1.27%	79.61%
Insufficient fastening of load	0.021333	1.18%	80.79%
Rupture of monoblock wheel	0.021008	1.16%	81.95%
Brake shoe or other object left under train	0.020936	1.16%	83.10%

4.5.3 Cost ranking of derailment cause categories by Pareto function

Top causes of derailments ranked by cost (Russia, USA and Austria only) are identified by using the same approach as in the previous section, where top causes of derailments per frequency of happening were identified using the Pareto function.

	Total cost /bil t km	Percentage as share of total	Pareto cost
Rupture of monoblock wheel	€ 29,597.49	14.03%	14.03%
Rail failures	€ 23,334.77	11.06%	25.08%
Brakes not properly checked or tested	€ 21,860.50	10.36%	35.44%
Spring & suspension failure	€ 19,108.82	9.06%	44.50%
Axle rupture, location not known	€ 16,920.56	8.02%	52.52%
Excessive track width	€ 14,547.43	6.89%	59.41%
Other or unknown rolling stock derailment cause	€ 10,315.39	4.89%	64.30%
Other mishandling of train including driver caused SPAD	€ 9,574.88	4.54%	68.83%
Substructure wash-out due to flooding etc	€ 7,859.06	3.72%	72.56%
Other track and superstructure failure	€ 7,656.13	3.63%	76.19%
Unspecified	€ 5,113.42	2.42%	78.61%
Wagon wrongly loaded	€ 4,219.92	2.00%	80.61%
Other operational failure	€ 3,884.61	1.84%	82.45%

4.5.4 Alternative final ranking of derailment causes

Each method of cause ranking gives slightly different results. Considering all methods it could be noted that the following causes appear in the most categorisations:

1. [I] rail failures
2. [RS] failure of bogie structure and supports
3. [I] excessive track width
4. [RS] hot axle box and axle journal rupture
5. [I] excessive track twist
6. [I] switch component structural failure
7. [O] wrong setting in relation to movement authority (points and turnouts)
8. [I] track height / cant failure
9. [O] wagon wrongly loaded
10. [O] brake shoe or other object left under train
11. [O] human factor
12. [I] failure of rail support and fastening
13. [RS] rupture of wheel
14. [RS] twisted or broken wagon structure/frame
15. [RS] spring and suspension failure
16. [O] speeding

Wheel-rail interaction is not analysed here as a separate cause because it is really a consequence of multi-causes. This will be researched more in WP3.

5 Main derailment causes

This section provides a basic explanation of 'key' derailment causes that have the most influence on derailments, either by number or cost. More detailed research into these causes will be completed in subsequent D-Rail work packages. More information about causes can be found directly in the investigation reports available on the D-rail website.

5.1 Train Handling

Train handling derailments are generally associated with excessive longitudinal forces such as developed by run in (high compressive forces) or run out (high tensile forces). These in turn can generate high Y/Q forces which result in a wheel climbing the rail and initiating the derailment. Improper braking can likewise result in high longitudinal forces introduced into the track. Contributing factors include (but are not limited to) high levels of longitudinal loading that can cause the couplers to break or pull-apart (high tensile forces) or which can cause high Y/Q values (high compressive train forces, particularly in a curve where they generate high lateral Y forces), improper braking , etc.

5.2 Infrastructure specific derailment causes

Rail failures
Rail failure derailments are generally associated with the fracture of the rail under a vehicle, usually under conditions of high dynamic loading. These types of rail failures are associated with internal defects that grow and reduce the strength of the rail section, making them more susceptible to fracture. Contributing factors include (but are not limited to) high contact stresses, high bending stresses, inadequate rail support, loss of rail section (usually due to excessive wear), high thermal tensile stresses, etc.

Switch failures.
Switch failure derailments include failure of a key switch component, usually under load, wheel climb in or through the switch, "picking a switch point" (wheel flange entering between a closed switch point and stock rail), loose or missing switch parts of switch mechanisms, improperly located guards, etc. Contributing factors include (but are not limited to) high dynamic impact loads, excessive vehicle-track dynamic movement, high Y/Q (or simply high Y or low Q), loose or missing bolts, rods or other parts of the switch mechanism, points that are not fully closed, improper guard rail geometry, etc.

Improper Track Geometry (excessive width, excessive twist, etc).
Track geometry related derailments are generally dynamic vehicle/track interaction related where the defects in the geometry (either individual or in a harmonic series) generate excessive movement in a vehicle (which can be improperly loaded or improperly performing). These are usually associated with high Y/Q values (or simply high Y or low Q), but can be also related to large deformation of the track under high Y or Q loadings. Contributing factors include defects in the track geometry (either individual or in some type of harmonic series), inadequate fastener strength,

improper vehicle loading, poorly performing vehicle, bogies or suspension, improper speed, etc.

Other track structure failure
Other track structure failures include failure of the rail fastener, sleeper, or substructure. These are usually associated with excessive dynamic loading. Contributing factors include high vertical (Q) and lateral (Y) loads, improper inspection and/or follow up maintenance, or in the case of track substructure improper drainage, excessive moisture.

5.3 Freight vehicle specific derailment causes

Wheel failures

Wheel related derailments are generally associated with the fracture of the wheel under a vehicle, usually under conditions of high dynamic loading. High temperature/overheating related failures are associated with the change in metallurgical properties of the wheel and the formation of thermally induced cracks. Contributing factors include (but are not limited to) high levels of loading (Y and Q) and associated high wheel stresses and stress related failure mechanisms (e.g. shelling), thermal overheating, excessive wear (thin flanges or worn tread), etc.

Axle Failures
Axle related derailments are generally associated with the fracture of the axle under a vehicle, usually under conditions of high dynamic loading. High temperature/overheating related failures are a major category of axle failures with the wheel bearings overheating and causing a “burn off” of the axle. Contributing factors include (but are not limited to) high levels of loading (Y and Q) such as due to poor suspensions or problems with the bogie frame, overheating of bearings, etc.

Spring and suspension failure
Spring and suspension failures are generally associated with improper loading or failure of the spring and suspension elements under load. They can include broken springs, failed elastomeric elements, etc. Contributing factors include high levels of dynamic loading (Y and Q), improper loading, improper inspections and/or maintenance, etc.

Journal rupture due to bearing damage
Bearing damage have many root causes such as overloading by dynamic effect due to wheel tread damage, current linkage, broken cage, metallurgical properties or mounting fault (choc, loss of fit…). Some derailments are due to wheel rupture (solid or tyre). In Europe tyre wheels are being removed from service over the coming years. **Type of wagon most prone to derailments**

It seems that the types of tank wagons are mainly involved in derailment have two characteristics which differ from other wagons i.e. the centre of gravity height and great torsional stiffness.

5.4 Operation specific derailment causes

Wagon loading
Wagon loading derailments are generally associated with either improperly loaded wagons that generate undesirable dynamic behaviour or which generate excessive loading which can result in failure of a wagon structural component or a track component. Improper loading includes uneven loading (end to end or side to side) or simply excessive loading or overloading. Improper loading whichresults in high centre of gravity also results in very adverse dynamic behaviour that can result in a derailment. Contributing factors include (but are not limited to) high levels of dynamic loading (Y and Q), to include unloading on one side (with consequently high Y/Q), excessive rocking of the wagon (increased susceptibility to track geometry faults such as excessive twist), high centre of gravity, improper welds or other structural components of the wagon which can fail due to overloading, etc.

Improperly fastener loads
Improperly fastened load derailments are usually associated with loads that are not adequately tied down, or fastened, or portions of the load that become loose and drag along the track, fouling switches or other track components and resulting in a derailment.

Human factor
The underlying cause of most derailments (even after what is identified as vehicle and infrastructure) is human factor.

<u>GB human factor analysis</u>
RSSB reviewed the 17 formal inquiry reports that DNV studied for their work submitted to the ERA, with the aim of establishing if there were any more underlying, contributory and causal factors relating to Human Factors and Operations. This review and a review of the top 10 analysis results from the UK Safety Management Information System (SMIS), highlighted underlying and contributory causes related to errors in procedures, planning, maintenance/inspection (train & track) and communication of information. These are the Operational and Human Factors issues that cause the incidents most frequently. The analysis highlights that, whilst technological solutions act as an aide in identifying when a derailment is more likely to happen, it does not address the underlying causes and only highlights the mitigating consequences. Whilst there is merit in developing new technological systems, it is also necessary to understand and address the root causes and the human failures associated with derailments.

5.5 Combined causes derailment data

Derailments have major and contributory causes that lead to accident. Again, many of these causes have underlying factors. In order to better understand these underlying factors it would have been necessary to review the individual investigation reports – many of which are confidential. To overcome this, it was considered appropriate to identify multi-cause accidents, from data sources available to the project and for which sufficient data was available.

It was clear that gathering more detailed data was not going to be easy either due to the large amount of derailments or simply due to a lack of adequate data in some instances. However, access was eventually provided to some investigation reports and these will be used in other WPs to define root causes of derailments. The information from many derailments are presented in a single database, available on the project website and available to project members, but it is suggested that when looking at combined cause derailments a direct study of the investigation reports is made. Where possible original reports are uploaded resulting in a selection of reports available on the D-rail website from:

- ERA, GB and Austria, which are public
- USA, Russia which are not public, and may only be used by consortium partners. Publication of any of these results must be approved by with the report owner.

Some single cause derailments have a clearly identified cause, e.g. broken wheel or journal rupture due to bearing damage, etc. For combined cause derailments it is not always easy to clearly identify their causes. Many parameters could be identified, all within tolerance levels (sometimes at the limit) but it is the combination that leads to derailment. The probability for a vehicle to derail is not 0 if all the parameters are at the limit.

While most railroads and national agencies tend to report derailments as due to a single cause or to a primary and additional secondary causes, in actuality many derailments are combined-cause derailments, where the combination of several contributing factors are necessary for the derailment to occur. Thus, if one of these contributing causes was not present, the derailment would not have occurred. Thus, while sometimes reported as a secondary cause, or in many cases not included as a cause, these contributing causes are critical to the occurrence of the derailment and to its prevention.

Very typical of this class of combined cause derailments are those associated with track geometry defects. In many cases, key additional contributing factors to these types of defects are speed, often within a “critical speed range”, non-uniform loading-which can include under loading of one side or end and overloading of the other side or end, poorly performing bogies, and excessive wheel or rail wear, particularly when they form a shallow angle that makes it easier for a wheel to climb the rail in a curve.

Likewise derailments in switches are very often combined cause derailments, with both the condition of the switch and the condition of the vehicle contributing to the derailment.

5.6 Shunting yards and sidings derailment data

The data available on marshalling yards is mainly from France (SNCF) and the UK (RSSB). SNCF and RSSB have made available brief analysis of this type of derailment occurring in their countries.

5.6.1 GB derailment data for yards, depots and sidings

Chapter 3.4 described the arrangements for the collection of safety data in the GB rail industry by means of the Safety Management Information System (SMIS). In

addition to the mandatory requirement to record all mainline derailments, a number of derailment events which take place in yards, depots or sidings are also recorded in SMIS. However, as this is not a mandatory requirement, the data can only be considered indicative of a probable larger number of derailment events which take place in yards, depots and sidings but are not recorded. It is considered likely that the yards, depots and sidings events recorded in SMIS are the more significant ones, but this distinction is not formally defined and is dependent on the voluntary use and interpretation by various train operating organisations. It is thought that the majority of derailments in yards, depots and sidings occur at low speed and cause little damage, or have low potential consequence.

The *Table 5.1* indicates the top 5 causes of derailment in GB yards, depots and sidings, based on the limited data available for the 6 year data period. This is based on the D-Rail categorisations of derailment causes. Where an event has more than one recorded cause a proportion has been used to split the record accordingly.

Table 5.1 GB top 5 causes of derailments in yards, depots and sidings, ranked by frequency

Cause Area	D-Rail Cause Category	Number of derailments in 6 year period *(Jan 05-Dec10)*
Operations	Human factors	25.1
Infrastructure	c. Switch component structural failure	5.5
Infrastructure	e. Excessive track width	4.0
Operations	c. Insufficient fastening of load	3.0
Infrastructure	a. Excessive track twist	2.5
	Other causes	25.9
	Total	66.0

As in the data for mainline derailments, Human Factors is the dominant cause of derailment in yards, depots and sidings. The top 5 causes represent over 60% of the yards, depots and sidings derailments.

All of the top 5 yards, depots and sidings derailment causes appear in the top 5 mainline derailment causes (ranked by frequency) apart from “c. Insufficient fastening of load”. This would suggest that the profile of derailment causes in yards, depots and sidings is broadly compatible with the profile suggested by mainline derailment data.

5.6.2 French data for shunting yards

SNCF had reported 201 marshalling yard derailments for our investigation period 2005-2010. They looked at causes of these derailments and concluded that:

- 92 % of marshalling yard derailments are due to operational error (human factor) or condition (backing movement);
- 5,3% are related to Infrastructure problem, mostly points and switches;
- and 2,7 % are related to rolling stock problem.

The detailed breakdown is shown in *Figure 5.1*.

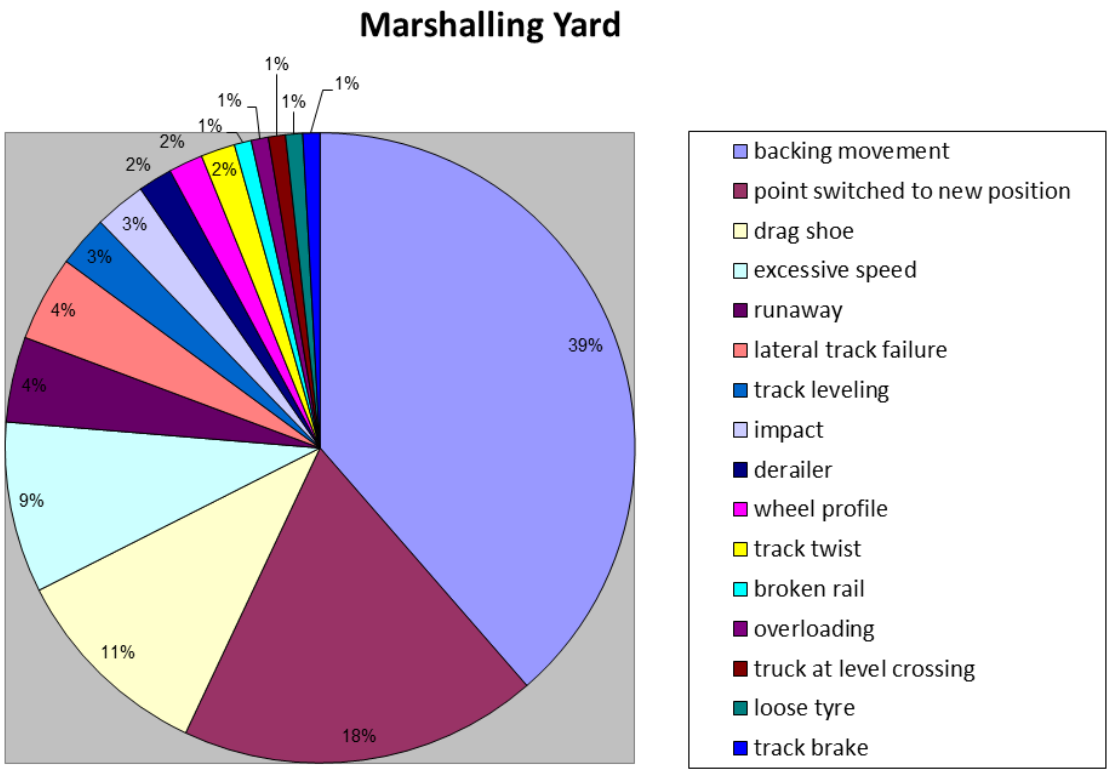


Figure 5.1 French distribution of causes for marshalling yard derailments

5.6.3 Conclusion about shunting yards, sidings and depots derailment data

These types of derailments are often not reported as many counties do not have a legal requirement to report them. Although they occur frequently, e.g. France had 201 derailments in 6 years, costs per derailment are low, so for France is estimated at only 1% of the cost of main line derailment. The main cause for these derailments is considered operational and mainly a result of human error. It is not recommended that the D-Rail project focuses any further, in its research, on these types of derailments.

6 Measuring and monitoring techniques

Current monitoring technologies and techniques in relation to both freight vehicles and infrastructure (wayside) are also included in the database, so each partner country is able to determine which causal effects are currently being monitored. Comparisons for each cause frequency and the monitoring technique for it, by country is available and to assist in establishing the effectiveness of these technologies in relation to freight operation and safety.

From available data we can conclude that most countries use monitoring techniques as: recording cars, track and vehicle-based, maintenance yard inspection methods and checks, and also visual inspection.

Causes and how they are monitored are presented in following

Table 6.1:

Table 6.1 Derailment causes and technologies, according to D-rail database.

Cause	Technology	How it is used
Hot axle boxes	Yes	Widely used
Track geometry	Yes	Widely used
Rail failures	Yes	Widely used
Improper loading of wagon	Yes	Widely used
Brakes	No	Widely used – maintenance checks
Switch	Yes	Not much used
High speed	Yes	Not much used
Spring & suspension failure	No	Not much used – visual check
Wheel break	No	Widely used – visual check
Axles	Yes	Widely used – maintenance checks

This is a preliminary analysis from supplied data. A more detailed review of monitoring technologies will be completed in WP4.

7 Conclusions

A result of WP1 has been the creation of a database containing freight train derailment information from USA, Russia, GB, Austria, France, UIC and ERA (DNV) for the period of 1.1.2005 -31.12.2010. Difficulty was experienced collecting the data to present in a single format due to the differences in the variety of data reporting criteria, consistency of reporting, structure of individual databases, classification of causes, etc. It was agreed to use the DNV classification of causes with slight modifications and concentrate on the summary number of derailments per year and costs, location of derailment (main line or shunting yard), and separation of single and multi-causes derailments. Derailments were therefore categorized into the following groups:

1. Derailments caused by *Infrastructure* failures
2. Derailments caused by *Rolling Stock* failures
3. Derailments caused by *Operation* failures
4. Derailments caused by *Weather, Environment and 3rd Party*
5. *Unspecified*

88% of derailments were successfully categorized into one of these four groups.

It was easier to categorise derailments into main groups than into subgroups. Initial analysis for world regions: USA, Russia and Europe was followed by individual European country analysis to help determine the main derailment causes in Europe. Within the world regions, Infrastructure causes are responsible for 40% of derailments, followed by rolling stock (33 %), and operations (25%). The spread between countries is sometimes huge due to differences in operation, track, rolling stock, etc. For example, USA's dominant cause is infrastructure at 50%. Track geometry is much more dominant in Europe as a whole (UIC and DNV) and other presented European countries, compared with USA and Russia, where the number of track causes is higher, and where it is the dominant cause is rail failures in USA. Within the infrastructure sub categories the following four causes are dominant in Europe: excessive track width, track height / cant failure, rail failures, switch component structural failure, excessive track twist.

Rolling stock derailment causes were more difficult to classify, although the following four groups could be identified: hot axle box and axle journal rupture, failure of bogie structure and supports, spring and suspension failure, wheel rupture. GB have had a higher percentage of derailments as a result of brake failings, the majority of which have been due to handbrakes left applied to wagons when moving on the mainline.

The most difficult category to classify was operations, where how to include the 'human factor' element presented a constant dilemma. Other dominant causes include: wagon wrongly loaded, point switched to wrong position, other mishandling of train including driver caused SPAD, brake shoe or other object left under train.

So overall the ranking of major derailment causes in Europe is:

1. Axle ruptures
2. Excessive track width

3. Wheel failure
4. Skew loading
5. Excessive track twist
6. Track height/cant failure
7. Rail failures
8. Spring & suspension failure

Most railroads and national agencies tend to report derailments as due to a single cause or to a primary and additional secondary causes. In reality many derailments are the result of combined causes (where the combination of several contributing factors are necessary), for the derailment to occur. Very typical of this class of combined cause derailments are those associated with track geometry defects. In many cases, key additional contributing factors to these types of defects are speed, often within a “critical speed range”, non-uniform loading- which can include under loading of one side or end and overloading of the other side or end-, poorly performing bogies, and excessive wheel or rail wear, particularly when they form a shallow angle that makes it easier for a wheel to climb the rail in a curve. Likewise derailments in switches are very often combined cause derailments, with both the condition of the switch and the condition of the vehicle contributing to the derailment.

Analysis of shunting yard derailments, where costs of derailment are comparatively much lower, showed the main cause to be operational, with the ‘human factor’ as a significant contributor. It is not recommended that subsequent WP studies focus on this area any further. The main causes of derailments in shunting yards (data from France and GB) and mainlines (Europe) is presented in *Table 7.1*. Where derailment is noted as occurring in shunting yards, other causes are generally not noted – hence other unspecified causes are excluded from the table below.

Table 7.1 Comparison between mainline and shunting yard derailment causes

Mainline causes		**Shunting yard causes**
Axle ruptures		Human factors
Excessive track width		Backing movement
Wheel failure		Point switched to new position
Skew loading		Drag shoe
Excessive track twist		Switch component structural failure
Track height/cant failure		Excessive track width
Rail failures		Insufficient fastening of load
Spring & suspension failure		Excessive track twist

These two categories are completely different, therefore the recommendation to analyse them separately. In shunting yards, operations and human factors are dominant. When considering the technical causes, track width and twist and loading appear in both categorisations.

Based on this analysis of derailment statistics, we can conclude that: developing new technologies and improving existing ones to aid the detection of major causes, improved planning and optimisation of inspections, where greater risk causes are tackled first, would result in fewer derailments.

8 Recommendations

Based on the analysis of the derailment causes, it can be seen there is a commonality of causes and mechanisms between all of the reporting groups which include Europe, US and Russia (with some exceptions as noted earlier). These mechanisms are very often related to clear and measurable parameters, which either directly or indirectly contributes to the derailment mechanism and/or cause. Many of these parameters are directly measurable, so that by identifying the derailment mechanism and its key contributing parameters it is possible to develop measurable parameters and/or conditions - the elimination of which would significantly reduce the risk of derailments.

These parameters can be directly related to the derailment cause, such as axle box temperature and its associated axle box burn-off derailment or indirectly related such as vehicle/track dynamic related derailments which often can have multiple contributing factors but generally have to have a high Y/Q ratio for the derailment to occur.

By examining those categories of derailments that represent the most common derailment causes (e.g. the top 5 or top 10 causes), and examining in detail the mechanisms associated with these derailments, it may be possible to identify key parameters that are both directly related to the derailment condition and that are directly measurable, either via wayside or on-board measuring devices or via an inspection vehicle.

By focusing on such key contributing parameters for the most common derailments and identifying both the parameter, its critical (or high risk) threshold, and a reliable and accurate measurement technology, it is possible to identify current or near term future technologies and measurement techniques that can be used to reduce the risk of these derailments. Furthermore, by understanding the fundamental mechanisms and the key influencing parameters, it may be possible to redeploy or modify existing technologies to more effectively reduce the risk of these derailments.

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Appendix 1: Complete breakdown of derailments

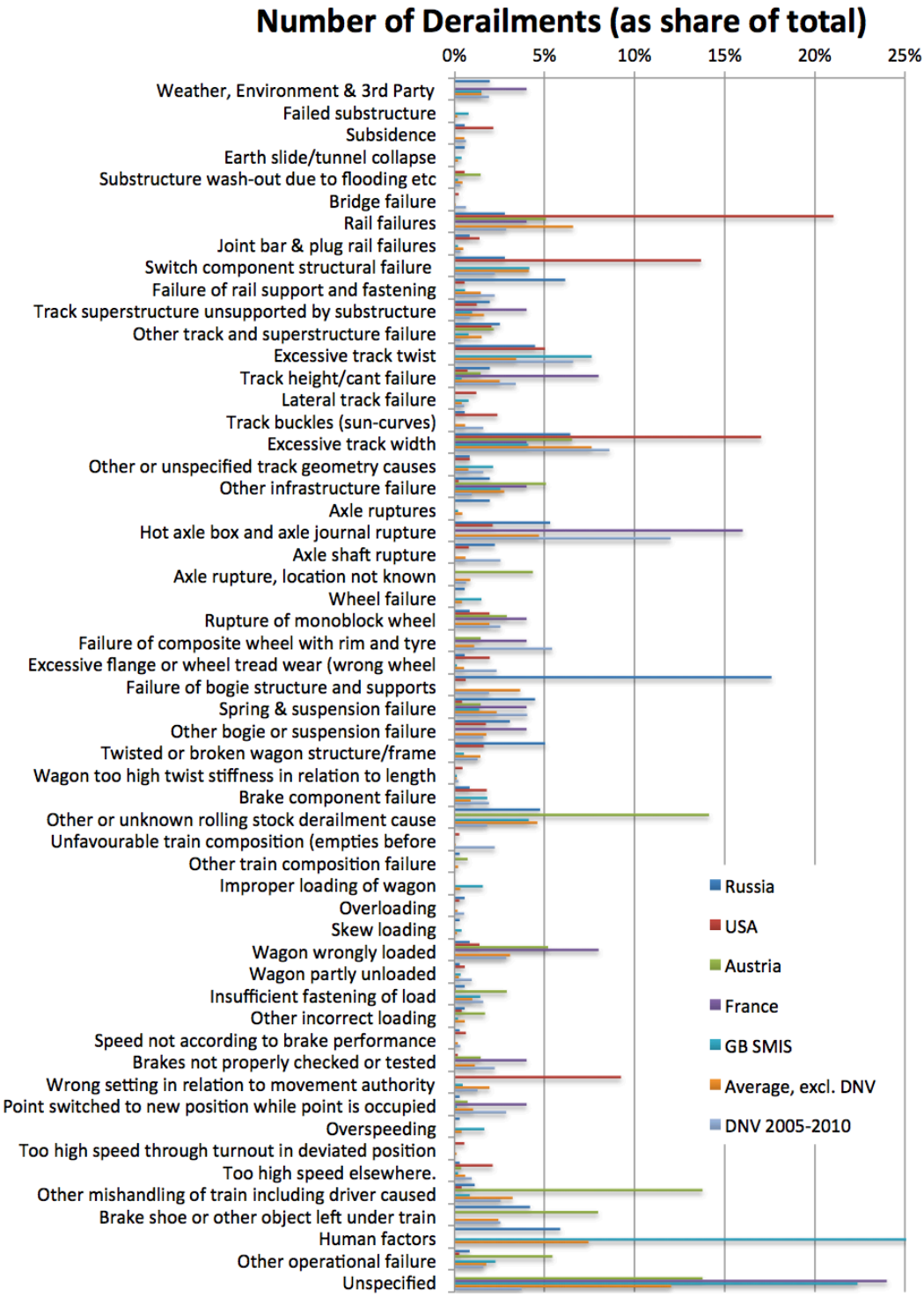

Figure A1.1 Number of derailments (as share of total) – complete breakdown.

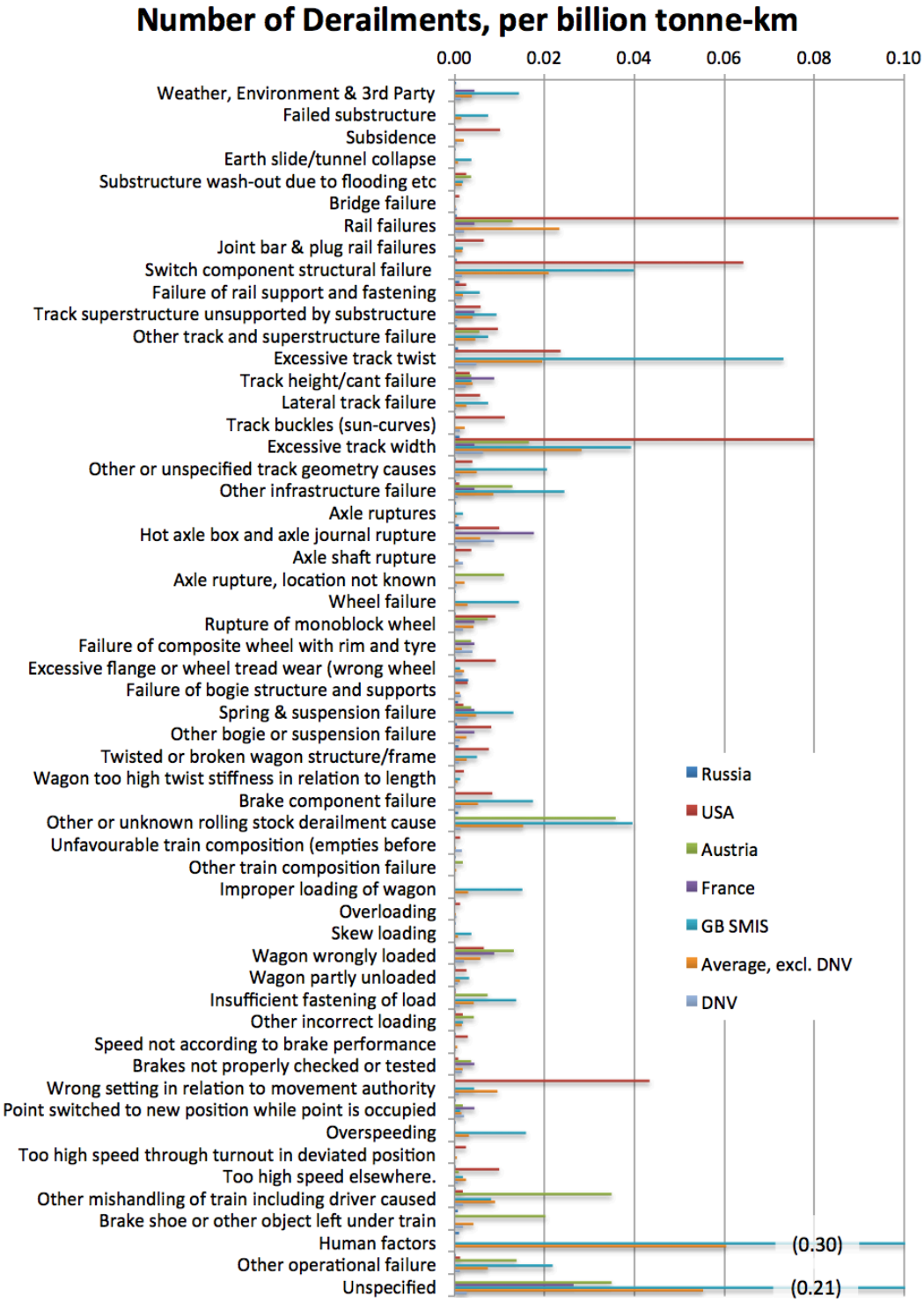

Figure A1.2 Number of derailments per billion tonne-km – complete breakdown.

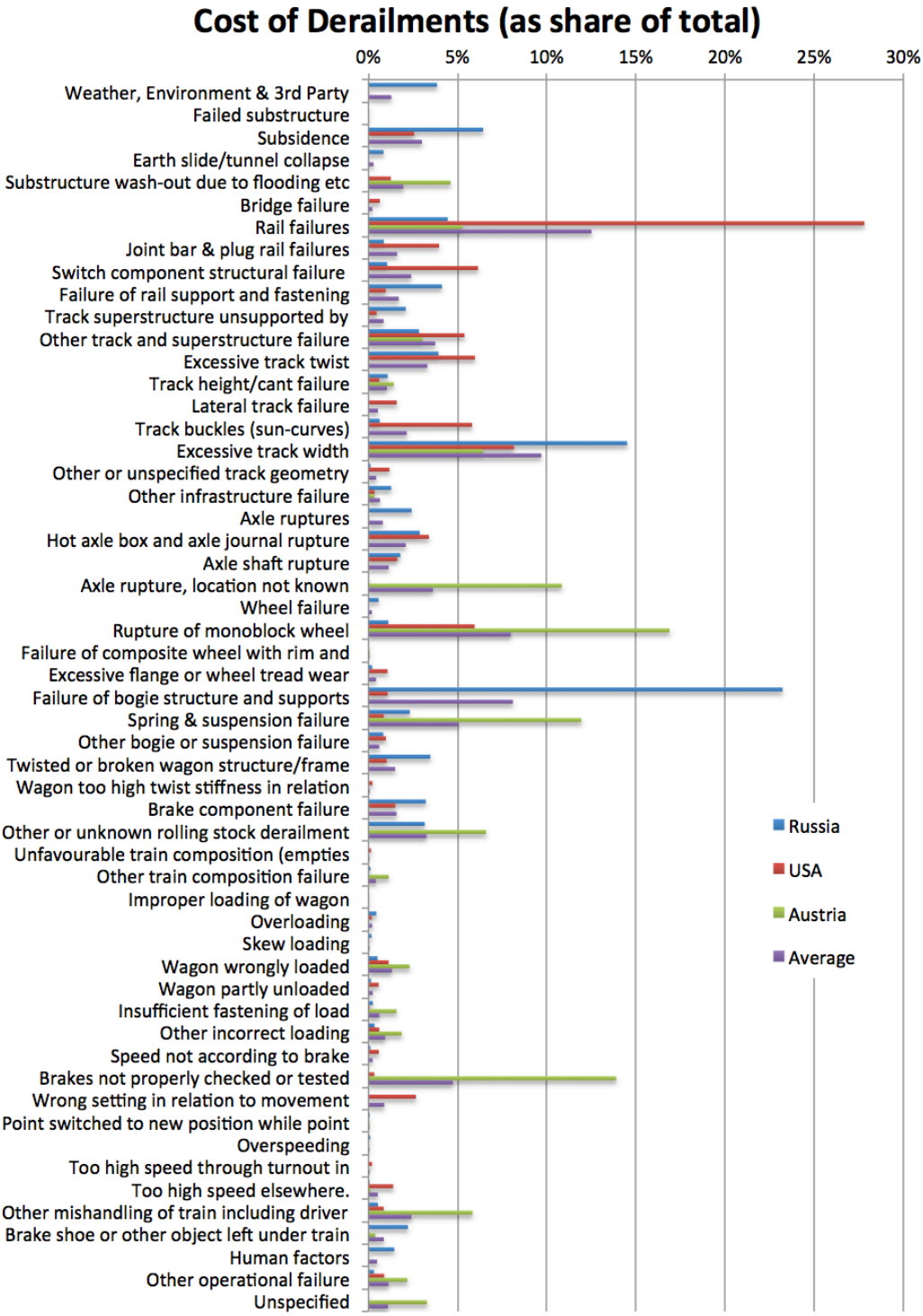

Figure A1.3 Cost of derailments (as share of total) – complete breakdown.