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Prospective Study into Harmonised Train Accident Precursors Analysis and Management

Final report

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Executive Summary

The European Union has adopted legislation to enable the gradual establishment of an integrated European railway area, both legally and technically. This involves the development and implementation of Technical Specifications for Interoperability and the application of a common railway safety framework.

The increased harmonisation of European railways may imply a harmonised approach to precursor monitoring and management by NSAs. In light of this, the aim of this study was to identify accident precursors that are theoretically sound and reasonably practical to implement at an operational and management level.

The specific objectives of this study were to:

1. Identify accident precursors and construct generic fault trees to display graphically the accident precursors for the six selected accident types:
    - i. Derailment
    - ii. Collision of trains
    - iii. Collision with obstacle
    - iv. Level crossing accident
    - v. Accidents to persons caused by rolling stock in motion (excluding suicide)
    - vi. Fires in rolling stock.
2. Gain insight into the accident precursors reported and monitored at NSA, IM and RU level across member states, with more detailed insight from RUs and IMs in a sample of member states, in order to understand current practice and the motivations behind it.
3. Develop a harmonised set of accident precursors for safety management at EU, NSA, RU and IM levels through the combination of theoretical accident precursor fault trees and actual, practical understanding of accident precursor reporting and monitoring.

Step 1 involved the development of fault trees for each of the six accident types. Information was used from:

- Research into existing rail risk models
- An extensive literature review including literature on rail accident precursors, rail risk models and risk models from other industries.
- Analysis of accident databases including those from UIC (the International Union of Railways) and ERA.

Fault trees are considered to be an appropriate, simple technique to effectively display the fault paths and sequences leading to an undesired event. Fault trees were populated with available risk data to provide a generic overview of key contributors to rail risk for each accident type. The fault trees indicate that there are 13 top level precursors which cause more than 20% of the risk associated with the accident type concerned.

Step 2 involved communication with RUs, IMs and NSAs primarily to establish which accident precursors are already monitored, how they are defined, and to collect any relevant information on precursor data and management. Telephone interviews were conducted with 13 RUs and 6 IMS across 12 different countries. A questionnaire was issued to NSAs (facilitated by ERA). The consultation suggested that rates of precursor monitoring by RUs/IMs are high. However, the extent of precursor monitoring did vary with some organisations monitoring very few precursors and others monitoring an extensive list. This may be due to varying degrees to

which different organisations have developed their precursor monitoring systems, or due to historical differences in the responsibilities among railway actors in different countries.

When precursors are monitored at a lower level in the accident causation chain, there are reported benefits to safety due to mitigating actions being more effective (they address hazardous events before any level of hazard is experienced, and for a wider range of accident types) and at typically lower cost.

RUs and IMs did report several challenges to precursor monitoring. The challenges experienced were wide-ranging, two of the emerging recommendations for improving precursor monitoring were to focus on greater automation and consolidation of data sources from across an organisation, alongside developing an improved organisational safety culture. With respect to the existing CSI framework of precursors, RUs/IMs would prefer further sub-categorisation of each type of the six precursors if they are to be used for operational purposes, with the sub-categories agreed at European level. Related to this, it was recommended that precursor reporting at European level should reflect the actual safety performance of each member state rather than allowing it to be inferred from raw precursor data that lacks context. Precursors monitored by the sampled RUs/IMs were identified and a list of frequently monitored precursors was developed.

Step 3 consolidated the previous steps and aimed to produce a harmonised set of clearly defined accident precursors that are likely to be accepted by the European railway community. Precursors identified in Step 1 as high risk contributors and those identified in Step 2 as frequently monitored were combined and precursors featuring in both steps were identified. This process resulted in the identification of two precursors for consideration by European legislators in the future, these being: collision of trains – runaway trains and accident to people caused by rolling stock – person on platform struck by protruding part of train (where it is not reported as a significant accident).

As this process yielded limited results, further consolidation was conducted. Precursors that featured in the fault trees in Step 1 and were monitored by at least one RU/IM/NSA were identified for each of the six accident types. It may be informative for all NSAs, RUs and IMs to consider these lists and the longer lists identified in Step 1 and Step 2 to identify additional precursors that may be informative in their particular context, rather than relying solely on those in this shortlist identified in Step 3. This led to a comprehensive list of precursor indicators that could be considered for monitoring at NSA and RU/IM levels. Provisional definitions for high risk precursors are suggested.

The current CSIs capture only a small part of accident causation mechanisms, and other precursors may well be helpful. Their careful selection is critical to ensuring that they do not distort performance or detract from other activities that contribute to improving safety.

Recommendations from RUs and IMs for precursors at a European level show a desire for greater sub-categorisation of precursors than is the case with the current CSIs if they are to be used operationally – lower level precursors are a preferred target for monitoring and taking mitigating action. It is therefore suggested that a clearer distinction might be required between precursors used for regulatory purposes and precursors used for safety management purposes when considering how precursors might be used.

To facilitate precursor monitoring and increase its value, there is a need to ensure that there is a good 'safety culture' across the rail industry. Gaining a clear understanding of safety culture, and how to facilitate it, is something that requires further consideration.

Promoting and developing the common taxonomy in the ERAIL database for the consistent classification of accidents and precursors may best be done by the facilitation of and consultation with appropriate stakeholders, not by regulation, and would be useful for a variety of reasons.

The use of precursors for operational reasons is vital to the proactive management of safety. Railway stakeholders across Europe are keen to share best practice with each other in this field, and ERA should make the most of this by continuing to work constructively and appropriately with stakeholders to develop a more harmonised European railway system.

1 Introduction and Background Information

1.1 Background

1.1.1 Legislative frameworks

The European Union has adopted legislation to enable the gradual establishment of an integrated European railway area, both legally and technically. This involves the development and implementation of Technical Specifications for Interoperability and the application of a common railway safety framework.

In 2001, the First Railway Package[1] (a suite of EU Directives) was introduced which opened the market for international freight, and represented an important step towards the harmonisation of railway operations.

The Second Railway package[2], specifically Directive 2004/49/EC, built upon previous legislation and set the stage for the establishment of safety parameters that would help maintain and improve safety throughout the restructuring process of EU railways. It introduced Common Safety Targets (CSTs) and Common Safety Indicators (CSIs) in order to allow for monitoring of developments in railway safety. These included:

- Indicators relating to accidents
- Indicators relating to incidents and near misses
- Indicators relating to consequences of accidents
- Indicators relating to technical safety of infrastructure
- Indicators relating to the management of safety

These were later revised and modified by Commission Directive 2009/149/EC.

As a result of the restructuring process, the European Railway Agency (ERA) has been tasked with reinforcing safety and interoperability of European railways. According to Regulation (EC) No. 881/2004 on establishing a European Railway Agency, the objective of ERA is:

> *"to contribute, on technical matters, to the implementation of the Community legislation aimed at improving the competitive position of the railway sector by enhancing the level of interoperability of railway systems and at developing a common approach to safety on the European railway system, in order to contribute to creating a European railway area without frontiers and guaranteeing a high level of safety."*

The Agency is therefore responsible for driving a harmonised approach to safety at different levels of operation.

1.1.2 Restructuring railway safety and Directive 2004/49/EC

Each member state with an eligible railway system is required by the Railway Safety Directive (RSD) to establish its own National Safety Authority (NSA) to oversee rail operations, and to

[1] The First Railway package includes Directives 2001/12/EC, 2001/13/EC, and 2001/14/EC (Office of Rail Regulation, Retrieved from http://www.rail-reg.gov.uk/server/show/nav.253#Second)

[2] The Second Railway package includes Directives 2004/49/EC, 2004/50/EC, 2004/51/EC, and a recommendation (Office of Rail Regulation, Retrieved from http://www.rail-reg.gov.uk/server/show/nav.253#Second).

issue safety certificates for railway undertakings (RU) and safety authorisations for infrastructure managers (IM). ERA has an advisory role to NSAs, as well as the European Commission, who are responsible for regulatory activities in this sector. Collectively, through the continuing process of hazard identification, risk assessment, control and monitoring, the rail industry can proactively plan for safety and intervene in the accident causation process.

In addition, the RSD tasked NSAs with the responsibility of reporting a series of Common Safety Indicators (CSI) which include indicators relating to accident precursors. **Accident 'precursors' are those incidents and events that would lead to a higher consequence undesired event if the conditions had been different.** All undesired events (not just those causing injury) represent failures in control and are therefore potential learning opportunities. In addition, according to the RSD, monitoring incidents as well as accidents is important as, 'other accidents and incidents could be significant precursors to serious accidents and should also be subject to safety investigations.' The information on precursors is monitored and assessed at three different levels: EU level (ERA), national level (NSA), and at an operational level (RUs and IMs).

ERA currently receives data on a set of six indicators that relate to precursors of accidents, as defined by Commission Directive 2009/149/EC. These indicators are the number of:

- Broken rails
- Broken wheels
- Broken axles
- Track buckles
- Wrong side signalling failures
- Signals passed at danger

CSIs and, specifically, indicators related to precursors of accidents are important tools for the continued monitoring of safety levels at the level of individual member states, but are deemed useful at all three levels of monitoring. On the other hand, NSAs, RUs, and IMs use these data in a more direct way, as they help to identify risk areas and potential risk control measures. Also, given that accidents on EU railways are rare events, information on precursor compliments accident data to provide a stronger basis for risk analysis and policy making at the organisational and national level.

The accident precursors specified within the CSI framework are, however, only part of a much larger, more complex set of accident causation chains. Indeed, there are likely to be many types of incidents that, given a different set of circumstances, could have led to an accident. In addition, a harmonized approach to interoperability, and more importantly, safety management of EU railways may also imply a harmonized approach to precursor monitoring and management by NSAs. In recognition of this point, this study took a Europe-wide sample of those precursors that are collected by NSAs, RUs and IMs that go beyond the six required by the RSD. Given that railway accidents are rare events, greater knowledge of accident precursors is a valuable tool to help monitor, measure and evaluate safety at country and operational level.

1.1.3 Evaluating accident risk

There are two key methods for managing accident risks: one is to use historical accident data to identify the accident types with the highest risk or frequency; the other is to develop a model to examine the potential causes of – or precursors to – an accident. Serious railway accidents are rare and just using historical accident data may conclude that the risk of such events occurring is remote or non-existent. To proactively manage accident risk, it is therefore important to look beyond the accident statistics and identify and estimate possible accident causation sequences (Appleton Enquiry Report, 1993). The frequency of such causes and sequences is large enough within the rail industry to provide a reasonable empirical base for estimating risks. The aim of a risk model is to determine how these minor events could interact to lead to a more serious accident.

Fault tree analysis is a graphical technique that provides a systematic description of the combination of possible occurrences in a system which can result in failure or an undesired event. It is essentially a failure oriented deductive type of analysis where the technique starts with a list of potential accidents and works down through the system to identify equipment failure modes and human errors that could cause the undesired event to occur.

By constructing fault (causal) trees for key railway accidents, fault paths can be constructed, and the minor events that could interact and lead to an accident can be identified. By monitoring the occurrence of such events, interventions can be implemented to significantly reduce the probability of a serious undesired event being realised.

1.2 Aims, objectives and scope of this work

It has already been highlighted that the increased harmonisation and interoperability of European railways may imply a harmonised approach to precursor monitoring and management by NSAs. In light of this, the aim of this study was to identify accident precursors that are theoretically sound and reasonably practical to implement at an operational and management level.

Firstly, the critical fault paths that contribute to the six accident types reportable under the CSI framework were identified. Those accident types were:

- Derailments
- Collisions of trains
- Collisions with obstacles
- Level crossing accidents
- Fires in rolling stock
- Accidents to persons caused by rolling stock (excluding suicides)

Having built a strong foundation through the development of fault paths, a further aim was then to understand which accident precursors were already monitored and reported by RUs, IMs and NSAs. The combination of the identified critical paths and knowledge of what is currently monitored helped to identify relevant accident precursors for safety management at European, national, and operational levels.

The Safety Systems Harmonisation Working group of the UIC Safety Platform has previously considered the requirements of Common Safety Indicators, as well as the related Common Safety Targets. These should be relevant, well defined, and affordable to monitor by member states (UIC Safety Platform, 2003). This study is aligned with these requirements and aims to identify clearly defined, transparent and useful accident precursors.

The specific objectives of this study were to:

1. Identify accident precursors and construct generic fault trees to display graphically the accident precursors for the six selected accident types. The fault trees identified

critical elements within the fault paths for the different levels of European safety management and governance (RU/IM, NSA and ERA).

2. Gain insight into the accident precursors reported and monitored at NSA, IM and RU level across member states, with more detailed insight from RUs and IMs in a sample of member states, in order to understand current practice and the motivations behind it.

3. Develop a harmonised set of accident precursors for safety management at EU, NSA, RU and IM levels through the combination of theoretical accident precursor fault trees and actual, practical understanding of accident precursor reporting and monitoring.

This report describes how these objectives were achieved.

Some limits to the scope of this study were set. Specifically, precursors associated with suicides on the railway, and precursors associated with malicious damage, trespassing, or vandalism to the railway, have been excluded in accordance with the Railway Safety Directive.

1.3 Methodology overview

The methodology comprises three steps which directly relate to the three aims described in Section 1.2. Figure 1 gives a broad overview of the methodology for the three steps.

Step 1 involved the theoretical development of the fault trees using knowledge from existing risk models, an extensive literature review and data from UIC (the International Union of Railways) and ERA. Step 2 involved communication with RUs, IMs and NSAs (facilitated by ERA), primarily to establish which accident precursors are already monitored, how they are defined, and to collect any data that can be shared for the purpose of this study. Step 3 consolidated the previous steps and aimed to produce a harmonised set of clearly defined accident precursors that are likely to be accepted by the European railway community.

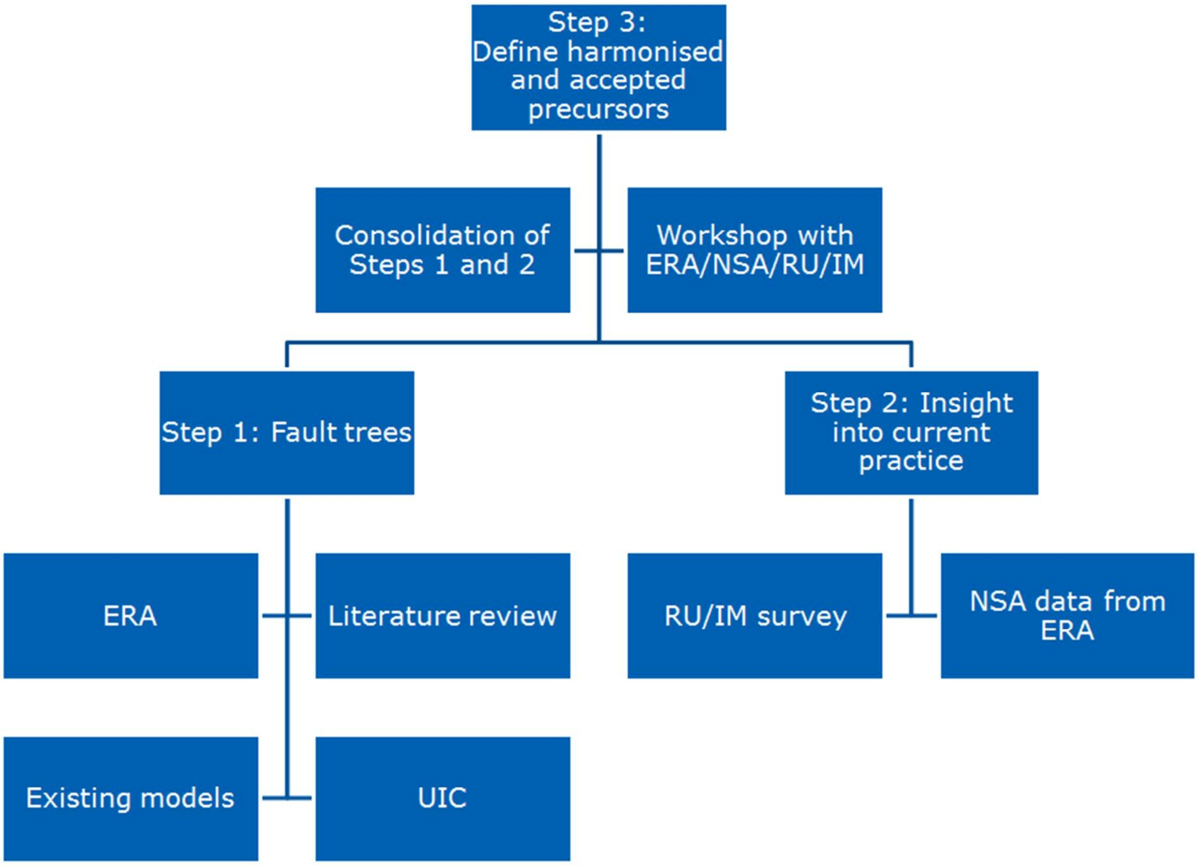

Figure 1: Methodology overview

2 Step 1: Theoretical development of fault trees

2.1 Aims of the theoretical basis

The overall aim of Step 1, the theoretical basis, was to develop fault trees for the six selected accident types:

- Derailments
- Collisions of trains
- Collisions with obstacles
- Level crossing accidents
- Fires in rolling stock
- Accidents to persons caused by rolling stock (excluding suicides)

The fault trees, based on theoretical understanding, could then be adjusted in Step 2 where an insight into current monitoring practices within EU countries was gained. The theoretical basis consisted of the stages summarised below; these are then explored in detail in the sections that follow.

2.1.1 Literature Review

The aims of the literature review were to ensure that the most appropriate method to construct and display the risk model[3] was selected, and to identify possible precursors for use in the risk model constructed in this project.

Relevant literature regarding accident precursors and causal fault tree research was identified, and existing risk models within the rail industry and other relevant industries were reviewed. Information was also sought on rail accident precursors, specific rail risk models and EU railway features to ensure the models were applicable to Europe as a whole. The information gathered from the literature was then fed into and informed the fault tree construction process.

2.1.2 Existing Risk Models

Rail risk models being developed within Europe and beyond were identified by ERA, RSSB, NSA contacts, TRL rail experts, the literature review and internet searches. Comprehensive risk models within the rail industry are still largely in their infancy so published literature was limited. Therefore, discussions were held, where possible, with stakeholders to gain a more in depth understanding of the model. Some stakeholders were prepared to share fault trees and data, providing valuable information for the construction and population of the fault trees. The main aim of researching accident precursor models was to identify precursors to rail accidents across Europe and to understand their associated hierarchy. The accident precursors and fault trees within the models informed the fault trees being constructed for this project to ensure they are comprehensive and representative of Europe, as far as possible.

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[3] A 'risk model' can refer to any quantitative representation of the potential for an accident to occur as a result of the operation and maintenance of all or part of a railway network. A risk model may include models that quantify the relationship between precursors and accidents, or other hazardous events that have the potential to cause damage or harm.

2.1.3 Development of Accident Precursor Inventory

An accident precursor inventory (API) was constructed for each of the accident types. All accident precursors identified through the literature, risk models, datasets or RUs, IMs and NSAs in Step 2 of the project were then included within this inventory. Where applicable, accident precursors were linked with the risk models that include them and the NSAs, RUs and IMs that currently monitor them. Definitions and varying terminology were also included in the API. The aim was to collect all information in one spread sheet to ensure that all relevant information was effectively fed into the fault tree construction process and, ultimately, the selection of suitable accident precursors to monitor.

2.1.4 Accident databases

The aim of examining accident databases was to identify any accident precursors that had not been identified from the literature review or existing risk models, and to extract relevant information that could be used to populate the constructed fault trees with relevant data.

2.1.5 Fault Tree Development

The aim of developing the fault trees was to graphically display the high level fault paths and associated accident precursors for each accident type. It was critical to ensure that the fault trees were appropriate for European railways so information gathered from the literature review regarding accident precursors and their interaction, and research into existing risk models, was fed into the construction process.

2.2 Literature review

2.2.1 Literature review methodology

A comprehensive list of search terms was established relating to accident precursors, rail risk models and the six selected accident types. In order to provide a manageable and relevant list, these were narrowed down and grouped into specific, interdependent categories, such as those relating to precursors and accident types. Some terms that might have been expected to be included, were intentionally omitted; for example, searching for the terms ‘incidents’ and ‘near miss’ would have provided far too many irrelevant articles to be of assistance with the literature review. For a list of grouped search terms used to conduct the initial literature search, refer to Appendix A. TRL searched transport related databases such as TRID and Science Direct to obtain 687 literature titles and abstracts.

To reduce the search findings to directly relevant literature only, inclusion criteria were set. Specifically, full articles were requested for any abstracts with information on:

- precursors for the six selected accident types;
- modelling of accident precursors;
- rail risk; and,
- variations in railways between EU countries.

Articles related to suicide, individual opinion, crash simulations, and system tests were excluded as these were beyond the scope of the study. While human factors contribute to a substantial proportion of rail accidents, identifying detailed accident precursors related to human factors was also beyond the scope of this study as the focus was on technical failures. Specifically, identifying and monitoring precursors relating to human factors did not fit with the goal of this study to identify and propose a set of harmonised precursors that could be realistically monitored across Europe. Whilst many technical faults may have a 'human cause' somewhere near the origins of a fault chain, be it in failed or ineffective maintenance and inspection regimes, or poor decision-making, it is the manifestation of human error in some form of technical failure that is easier to monitor consistently and manage effectively, rather than the frequency with which human errors occur.

82 papers were considered to meet the established criteria and full papers were requested. In addition to this comprehensive search, additional literature searches were conducted specifically for risk models outside the rail industry including in road transport, civil aviation, water transport and the nuclear industry. Relevant literature titles were also supplied by ERA, RSSB, representatives of NSAs, rail organisations attending ERA's Safety Performance Working Party and rail experts within TRL.

2.2.2 Rail risk modelling and accident precursors

The introduction of the Railway Safety Directive in 2004 marked a change in the way the safety of railways across Europe is managed. It introduced the requirement to set up a safety management system as a tool for risk management and mitigation at operational level. Common Safety Indicators were also designed for reactive monitoring at the EU/country level only. This strategy has not only changed the way organisations manage their safety data, but it has also brought about a change in their safety culture. For example, according to the Dutch policy for rail safety (Tweede Kadernota voor de veiligheid van het railvervoer in Nederland, as cited in Roelan, 2008, p.91), all design plans and resolutions on rail transport should include an integral safety plan or safety case.

Risk models are increasingly being used within the rail industry to estimate the risk associated with key hazardous events and to ensure interventions are implemented to reduce the risk of avoidable accidents. However, the literature review revealed that rail risk models are largely still in their infancy and limited published material exists regarding their development and content. Nine relevant rail risk models were identified in the literature review and through discussions with rail industry experts. These are detailed separately in Section 2.3.

Specific accident precursors detailed within the literature reviewed were input directly into the accident precursor inventory to ensure efficient sharing of critical information for the fault tree development.

Table 1 contains a summary of the findings from the eight key pieces of literature reviewed regarding rail risk models and accident precursors.

One of the more relevant set of findings emerged from a study on metro rail safety identified by the database search. The study was carried out by Kyriakidis, M., Hirsch, R., & Majumdar, A. (2011) from the Centre for Transport Studies at Imperial College London. The study surveyed several metro networks from the Community of Metros (CoMET) and Nova — two metro benchmarking groups comprising several countries — in order to assess the relationship between the use of a Safety Maturity Model (SMM) and actual safety. The SMM targets a number of safety issues, including behavioural change, but also technical, operational and methodological changes to improve safety at metros. The maturity index (i.e. the level of monitoring and managing of particular measures, including precursors) was negatively correlated with the number of injuries per metro. Nonetheless, results of the study may be of limited applicability as several top-level hazardous events in metro lines differ from those found in heavy rail (e.g. flooding has greater consequences for metro networks). In addition, the published literature has insufficient detail regarding which metros participated in the survey, the monitoring practices used, and the differences in safety culture.

Similarly, a recent article by Hirsch and Xiang (2012) summarises research that, according to the authors, shows that the focus of safety indicators should not only include minimising negative events, but also promoting positive activities (e.g. first aid training for staff) to develop the SMM further.

As shown in Table 1, some of the relevant studies identified have been conducted in the United States, where track and human factors are considered to be the main precursors to accidents (Federal Railroad Administration, 2005). It seems that rail accident prevention research is an emerging theme in the US as national authorities have proposed to carry out a large study on accident precursors. This is as a part of a number of national projects aimed at improving safety data across all transportation modes (Safety data initiative, 2002). Although an extensive search of the Bureau of Transport Statistics website (RITA) did not yield any information regarding the status of this project or any preliminary results, the commissioning of such a project alone shows that the need to understand precursors and develop better monitoring practices is of international concern. In addition, the studies from the US included in Table 1 show that this country plays an active role in producing research to help prevent rail accidents.

Some of the literature related to statistical modelling of accident risk. For example, a study in Finland explored the use of a risk assessment approach for freight (Tuominen, Sirkiä, Kallberg, Rosqvist, & Kotikunnas, 2006). A research team in Australia used Petri Nets, a graphical and mathematical modelling tool applicable to many systems (Murata, 1989), to assess the risk posed by heavy vehicles at level crossings (Siti Zahara, Yue & Somenahalli, 2010). Similarly, a study in the United States sought to create a model to predict the probability of collisions at level crossings (McCollister & Pflaum, 2007).

Current methods of calculating accident risk were also discussed within the reviewed literature. One study by Fukuoka (2002) argues that fault tree and event tree analysis may not be able to assess risk adequately as, according to the author, it presents limitations in accounting for the dependencies between the multiple sub-systems necessary to operate a rail network. An alternative approach was proposed by the author, however, there was not enough evidence to support any advantage of the proposed approach and was therefore not considered relevant to the current study. Further research by Zhang, Guo & Liu (2010) proposes the use of a combination of Fault Tree analysis and the Markov State Transition Model (related to the states in the micro-computerised automatic block signalling system between railway stations) to calculate risk frequency. The study did provide details of a partial fault tree model for a wrong cancelling block; however as this was designed as an example, no detailed frequency or risk data was provided that could be used to feed into existing fault trees. Although the findings of both studies expand upon the current state of modelling rail accidents, the present study is not concerned with the evaluation of these methods. In addition, the applicability of these models to Europe may be limited as both studies were carried out in Asia.

Another area of focus in the literature was the factors that may affect severity or outcome of rail accidents. Such factors included train length (Schaffer & Barkan, 2007), vehicle size (Chadwick, Saat, & Barkan, 2012), and dangerous goods car placement (Bagheri, Saccomanno, Chenouri, & Fu, 2011). In these examples, the literature described findings that could be used to develop event trees: these are logic models that identify and quantify the possible outcomes — and the factors that would influence these outcomes — following an initiating event (such as a derailment). The current study focuses on developing fault trees: these identify the logic relationship between failures of components and sub-systems that may ultimately lead to a top-level event such as a derailment. As such, these studies could not contribute relevant knowledge, although it is clear why they emerged in the literature search, given the common terms that are used in event and fault tree analyses.

Further research was focused on preventative strategies, for example the testing of systems and technology to help prevent accidents. One approach taken was to analyse individual components of the network, for example the effects of heavy axle loads on steel bridges (Unsworth, 2003), or techniques to improve safety such as crash energy management (Tyrell & Perlman, 2003), and the development of tools able to identify locations producing unsafe vehicle performance immediately (e.g. TrackSafe) (Zarembski, Bonaventura, & Palese, 2006).

A few of the articles sourced for the literature review highlighted the differences that exist between the railway systems across the member states of the EU. The rail systems of the different member states will have key differences that could affect the construction and applicability of the fault trees generated by this study, as well as the feasibility of introducing new precursors for future monitoring.

The key variations between EU railways noted in the literature reviewed are as follows:

- The extent of railway liberalisation and private sector involvement is variable. The ownership status of an RU or an IM may influence how it monitors and shares precursor data currently (where they are collected), and indeed the ease with which additional precursors could be monitored in the future. In an open, competitive rail market, the willingness and financial ability of an RU or IM to engage with using precursors may be influenced by how it is owned and funded – the different ownership and funding models may have a positive or negative effect on engagement with precursors. Such factors may be moderated by the existence of other organisations that are funded to provide mutual assistance and benefits to market players, such as Magyar Vasuti Egyesules (Hungarian Railway Association) and the Rail Safety and Standards Board (RSSB) in Great Britain.
- The technical development of rail systems is diverse across Europe. Traffic management systems are one such factor. The European Rail Traffic Management System (ERTMS)[4] was introduced to develop interoperable traffic control systems for all member states. Several member states have introduced the new systems, such as Spain and Denmark, or are in the process of introducing the systems. Spain has the largest area of application of ERTMS in Europe and is the first to implement it on commuter lines. Similarly, Denmark was the first EU country to attempt a complete conversion of a national network to the traffic management system within the European Train Control System (ETCS). However, some countries had already introduced traffic management systems that provide varying degrees of protection. For example, Great Britain has trains that are equipped with the Train Protection and Warning System (TPWS), whilst German and French operators have also introduced modern train control systems. Some of the literature drew attention to these differences, as well as to the problems (the costs and perceived lack of foreseeable advantages) of changing to ERTMS if a similar system was already in use. It is likely that the technical advantages afforded by these systems will impact on the precursors for some rail accidents (such as train-train collisions) and affect the universal relevance of some fault trees.

[4] ERTMS is a set of European standards for Electronic Train Control Systems (ETCS) and radio communications. It was introduced to enable and simplify interoperability in traffic control when trains cross borders.

- The literature also identified that level crossing accidents are a significant concern in most countries but the frequency with which they occur – and the reasons why – vary substantially. One of the differentiating factors is the prevalence of level crossings within a particular country; some countries have many relative to their network size, and some countries have few. Differences also existed in how level crossing protection was defined. Such differences will have an effect on the range and relevance of precursors identified for certain accident types (such as collisions with obstacles). Elliott (2008) found that:

  > *The dominant factor that determines the level crossing accident rate is the behaviour of road users.*
  >
  > *The number of level crossings in the country is also relevant but there is little evidence that the intensity of use of the railway [i.e. the number of trains that pass through the level crossing] is significant.*

2.2.3 Risk modelling in other industries

Detailed information about rail risk models in published literature is limited. Therefore, it was necessary for the purpose of this study to widen the literature search to include other comparable industries. Literature regarding risk modelling within road transport, civil aviation, marine industries and the nuclear industry was reviewed.

Road accidents account for the majority of accident casualties in transport. Due to the prevalence of road accidents there is a large amount of data that can be monitored and analysed to identify high risk areas or activities. Therefore accident prediction models within road transport largely rely on statistical analysis and are more data led than fault trees. For example, the first accident prediction model developed by Persuad (1993) presented relationships between the number of accidents and the traffic flow expressed as average daily traffic (ADT) and hourly volume. Hauer (1996) subsequently calibrated other models to predict crash frequency (number of crashes per year) on multilane urban roads by using variables listed as AADT (Annual Average Daily Traffic), the percentage of trucks, slope, horizontal curve length, roadway width, type and width of clear zones, danger levels of road shoulders, speed limits, points of access, and the presence and nature of parking areas. The results demonstrated that AADT, the point of roadway access, and the speed limits were the significant variables for predicting crash frequency. Statistical tests were developed by the same author to test the statistical significance of the obtained results. Therefore models relying on accident statistics have been developed but not specifically regarding the prediction of low probability, high consequence activities. Exposure and user behaviour are clearly important predictors of road accidents; there is little reason to believe this is different in terms of predicting rail accidents.

The European Aviation Safety Authority (EASA) is the safety regulator for civil aviation, and sets the safety standards for airports, aircraft and crew. Airline accidents are rare, so empirical data on accident frequencies and consequences is limited. Aviation safety regulation contains quantitative safety requirements, leading organisations to create causal risk models to demonstrate compliance with the required safety targets.

Civil aviation was the first transport mode to adopt quantified risk modes on a large scale (Lloyd and Tye 1982). There are a large number of causal risk models within civil aviation due to the varying needs of the end user. Local users such as individual airlines or airport authorities need models that accurately describe their local situation. Local users require a model that is narrow in scope and deep in detail, while models for general users should be broad in scope and shallow in detail (Roelan, 2008). Overall an effective causal risk model should:

- Include risk indicators
- Provide reproducible results
- Represent the system as a whole
- Have quantitative output

The methods used to develop fault trees within civil aviation include:

1. Boolean trees

   Boolean trees include fault trees and event trees. Fault trees graphically display a variety of parallel and sequential combinations of faults that can lead to an undesired event. Event trees represent the possible consequences following a hazardous event.

2. Bayesian Belief Nets

   These graphs allow multi-valued variables rather than the binary events in a fault tree.

3. Petri Nets

   This is a graphical and mathematical modelling tool for describing and analysing distributed systems. A fault tree is primarily constructed to communicate a model or thinking to the end user and effectively, and simply display cause-effect relations. The method used must be guided by the requirement and complexities required by the end user (Roelan 2008).

As with aviation, maritime accidents are rare, therefore creating significant gaps in accident data. According to Goss (1994), the maritime industry has traditionally been more concerned with damage to infrastructure (including ports and vessels) than safety. However, increasingly probabilistic risk assessment methods are used, especially within the required safety case that includes identification and assessment of the risks of major accidents (DNV, 2002).

Within the nuclear industry, the desire to meet risk targets and to evaluate the effects of design improvements of nuclear power plants, led to the introduction of probabilistic risk models. The first full scale application of these methods was undertaken in the Reactor Safety Study WASH1400 (NRC, 1975). The use of fault trees and event trees coupled with an adequate database is commonplace within the nuclear industry and is considered the best available tool to quantify probabilities.

2.2.4 Summary

This review indicates that risk modelling is most commonly conducted in industries where major accidents are rare and historical accident data is not available. Risk models must be appropriate for the end user with regards to scope and detail. High level risk models for general use are likely to have a wider scope but less detail. Fault trees are considered to be an appropriate, simple technique to effectively display the fault paths and sequences leading to an undesired event.

Civil aviation and the nuclear industry have the most widely used risk models. This is largely due to heavy regulation and the requirement for probabilistic risk assessment. There is not, however a 'one size fits all' approach to risk modelling but a number of models developed to incorporate local conditions, factors and culture. Rail industry regulation has historically focused on compliance but a shift in regulation has led to the development of rail risk models to identify and quantify precursors to accidents. Most of the identified risk models are in their infancy and published literature was limited.

Discussions were held with stakeholders to ensure all available data were gathered and lessons learned. More detailed rail risk model information is in Section 2.3. Precursors identified in the literature review were input into an Accident Precursor Inventory; this is described in Section 2.4.

Table 1: Summary of Relevant Literature

Author(s)	Year	Country	Issue	Type	Method	Conclusions	Specific precursors/ accidents mentioned	Limitations
Hirsch, R., & Xiang, L.	2012	Various	Safety/ prevention	Study	Interviews and documents were obtained from CoMET metros, including QRA and precursor monitoring.	a) Existence of platform doors, fire extinguishers, CCTV, and first aid trained staff on station yielded positive correlations with better safety; b) Focus of safety indicators should change from measuring and minimising negative events (such as precursors) to promote positive activities.	n/a	Metro data. Not enough information on the study methods and results. No mention of precursors collected by CoMET metros.
Kyriakidis, M., Hirsch, R., & Majumdar, A.	2011	Various	Analysis of accident precursors	Study	Risk management experts at 11 CoMET and Nova metros completed a questionnaire based on the Safety Maturity Model (SMM).	Improvements in the safety of metros are related to the exchange of best practices, and as a result of the accident precursor monitoring program started in 2000.	Signals passed at danger, manual (degraded operation), signal failures, falls on stairs, falls on escalators, smoke on trains, trespassers, & station total closure.	Focus on reasons for improvements in incident/ accident rate. Some indicators/ precursors may be different for metro than for heavy rail.
Zhang, Y., Guo, J. & Liu, L.	2010	China	Risk frequency estimation	Study	Uses failure data of basic events related to micro-computerised automatic block system between railway stations in China to propose an improved method for risk frequency estimation	Comparing the state-based fault tree model and the primary (basic) fault tree model, authors conclude that the former was more scientific and accurate in analysing the risk frequency of the dynamic stochastic system.	Precursors listed for 'wrong cancelling block' in an automatic block system: software of block host computer failed, software of axle computer failed, wrong operation, electromagnetic disturb, 4050 module 1 failed*, 4050 module 2 failed*, 4050 module 3 failed*, 14520 module 2 failed*, state of information relay is wrong, transmission signal break, the message is wrong. *no additional information was provided	The focus of the study was on the technique used for the risk frequency estimation; the fault tree provided was only an example and it was specifically for 'wrong cancelling block'. Little information on precursors listed was provided.
Schutte, J., & Klinge, K.A.	2008	Germany	ROSA	Report	57 'starting point hazards' have been identified. These capture potential hazards in the operation of the rail network. Fault/event trees have been established with these data.	n/a	Among the 57 identified are: wrong determination of speed limit, broken switch components, broken wheel/ axle, failure of vehicle frame/ car body, person falls out of door, and trespassing.	Report does not include the fault/event trees, or any detailed information on these.

Author(s)	Year	Country	Issue	Type	Method	Conclusions	Specific precursors/ accidents mentioned	Limitations
Federal Railroad Administration	2005	USA	Safety/ prevention	Report	Analysis of train accident data.	a) Accidents caused by defective track or human factors comprise over 70% of train accidents; b) the top ten human factor causes accounted for 58% of all human factors accidents (2001-2004); c) Implementation of a 'close call' reporting system (example of aviation) that shields reporting employees from discipline may help reduce risk.	Top ten human factor causes: switch improperly lined, shoving movement/ absence of person on point, shoving movement/ failure to control, cars left out to foul, switch previously run through, failure to secure hand brake, failure to apply sufficient hand brakes, passed couplers.	US data. Focus on the discussion of the action plan, little detailed information on crash statistics, or precursor information.
Barkan, C.P.L., Dick, T., & Anderson, R.	2003	USA	Derailment/ hazardous materials	Study	Analysis of railroad derailment data.	Speed and number of carriages derailed significantly relate to the probability of hazardous materials release.	Some precursors leading to most accidents (as identified by the study): broken rails or welds, track geometry, bearing failure, wide gauge, buckled track, train handling, and broken wheels.	US data. Specific to the potential release of hazardous material.
Dick, C.T., Barkan, C.P.L., Chapman, E.R., & Stehly, M.	2003	USA	Prediction of broken rails	Study	Databases were analysed to identify variables most strongly correlated with service failures.	a) Broken rails are the leading cause of severe accidents in the USA; b) The service failure prediction model (SFPM) shows promise in improving the ability to predict broken rails.	Broken rails.	US data. Focus on predictability of a specific accident precursor indicator.
Liu, X., Barkan, C.P.L., & Saat, R.	2003	USA	Derailment/ prevention	Study	Analysis of parameters for predicting derailment risk.	Higher track classes are statistically correlated with lower derailment rates; however, upgrading tracks may increase the risk of other precursors.	Broken rails or welds, track geometry, bearing failure, broken wheels.	US data. Focus on a specific intervention (upgrading track class) for preventing derailments.

2.3 Existing Rail Accident Risk Models

When identifying a harmonised set of precursors, it is important that, as far as possible, they are appropriate across Europe, not just to a limited selection of member states. Through the literature review and discussions with stakeholders, the following models were identified and researched:

1. GB Precursor Indicator Model (PIM)
2. Det Norske Veritas (DNV) freight train derailment precursors
3. Rail Optimisation Safety Analysis model (ROSA)
4. Risk landscape model – Federal Office of Transport for Swiss Railways
5. Irish Rail Safety Risk Model
6. Generic Error Modelling System (GEMS)
7. Safety Risk Model (SRM)
8. London Underground Quantified Risk Assessment (LUQRA)
9. Korean Risk Assessment Models

In addition, relevant information on the Danish accident reporting system was also obtained.

2.3.1 GB Precursor Indicator Model (PIM)

The PIM was developed in 1999 to measure the underlying risk from train accidents by tracking changes in the occurrence of accident precursors. The precursors tracked in the PIM indicate the risk of accidents happening, even though they do not often result in an actual accident. The model monitors the risk to passengers, the workforce, and members of the public from three main events:

- Train collisions (including those with other trains, buffer stops, and road vehicles);
- Train derailments; and,
- Train fires.

The PIM provides a month by month review of the main elements of train accident risk, and is normalised to take account of the increase in train-miles travelled over the time the model has been measuring the risk.

Each precursor has its frequency measured and is then weighted to place its relative contribution correctly within the total train accident risk. This involves referring to the Safety Risk Model (SRM), which is updated every few years in a major reassessment of the industry's risks but, in the interim years, the PIM provides a measure of how large an effect each precursor is having on train accident risk.

The PIM is a model of risk change and as such is rebased to a value of 100 at a convenient 'benchmark' point in time. The benchmark point was chosen to be March 2002. This simply means that the values are presented relative to those in 2002; these could be rebased simply to any other point in time for which data exists.

The precursors covered by the PIM fall into six main groups, encompassing 27 separate sub-groups and 45 lower level groups. The six main groups are:

- Infrastructure failures
- Irregular working
- Public behaviour at level crossings
- Objects on the line
- Signals passed at danger
- Trains and rolling stock

Figure 2 presents the 27 sub-groups and illustrates how they are aligned with the six main groups.

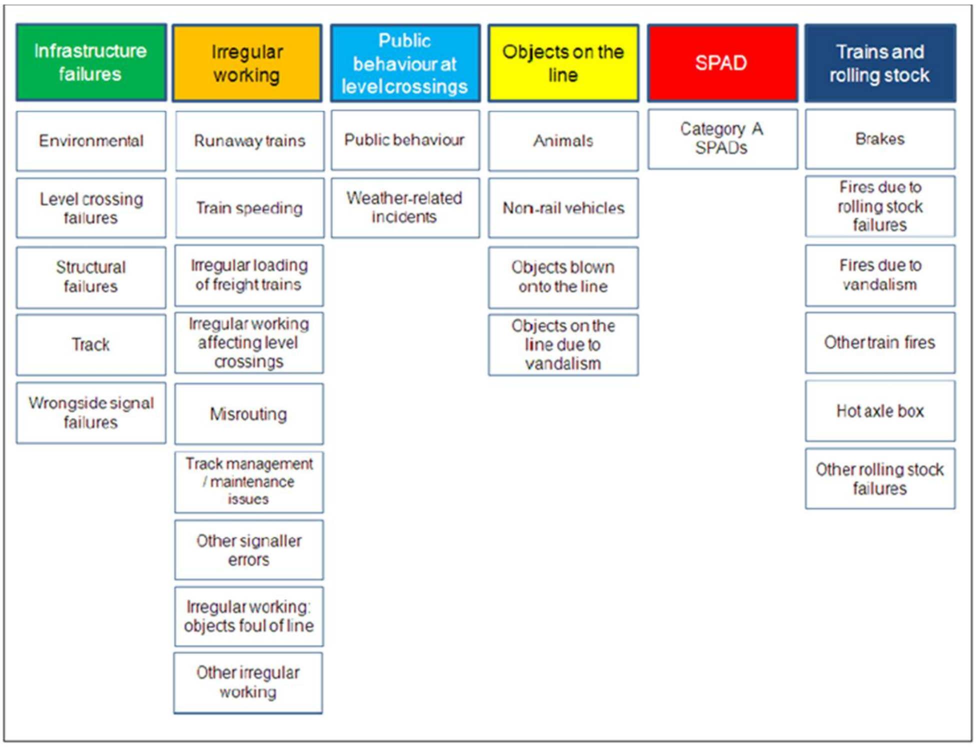


Figure 2: Overview of the PIM (source: RSSB Annual Safety Performance Report 2011/12)

2.3.2 Det Norske Veritas (DNV) freight train derailment precursors

DNV completed a study on behalf of the ERA to identify prevention and mitigation measures that could reduce the risk of freight train derailment. The study was twofold and involved identifying the measures currently in use as well as understanding the reliability, maintainability, availability and therefore effectiveness of each measure. A 'bow tie' approach was used where both fault trees and event trees were constructed, the fault trees showing the fault paths leading to an undesired event, and the event trees showing the potential outcomes once an undesired event is realised. The preventative measures can easily be linked to a particular fault path and graphically show how the measure breaks the accident causal chain. The precursors identified within the fault trees were included within the accident precursor inventory described below to ensure that the fault trees are comprehensive and fit for purpose. Figure 3 shows an example of a fault tree for derailment used within the DNV report.

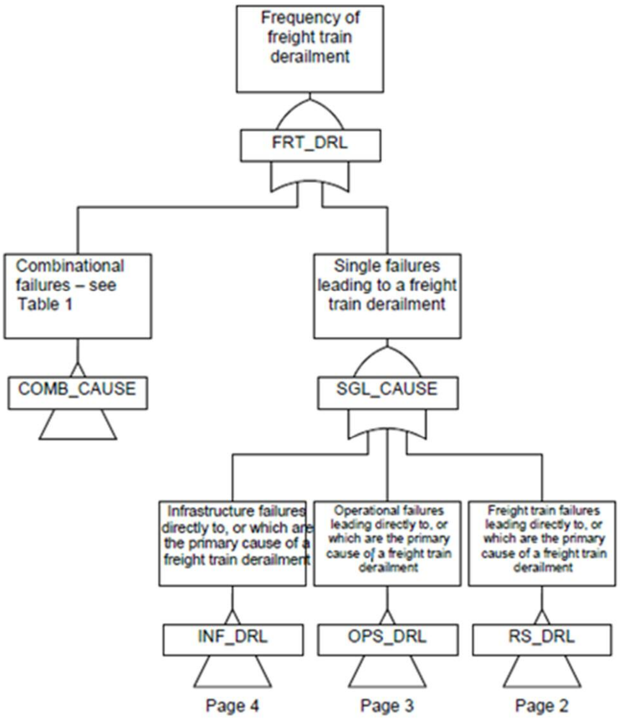


Figure 3: DNV derailment fault tree example (source: Assessment of freight train derailment risk reduction measures, DNV, 2011)

2.3.3 Rail Optimisation Safety Analysis (ROSA)

The Rail Optimisation Safety Analysis (ROSA) model was developed jointly by Deutsche Bahn and SNCF. Its purpose is to analyse the safety characteristics at a complete network level, and to identify the potential to optimise safety, quality, and costs. It covers four areas:

- Hazard and consequence analysis
- Impact analysis
- Cost-benefit analysis
- Validation

Working packages one and two (hazard and consequence analysis, and impact analysis) resulted in various models for estimating safety. These included the use of fault tree analysis to determine the likelihood of accidents, and the Barrier Quantification Model to determine what safety measures (barriers) are implemented and their efficiency rates.

The ROSA model is centred around a list of 'starting point hazards' which capture all potential hazards associated with the operation of a network derived from a full fault tree preliminary hazard analysis (Schütte & Klinge, 2008). Fifty-seven starting point hazards were identified, which were individually developed into event trees to develop possible consequences, in order to transfer these into a manageable number of accident categories (e.g. derailment). Potential barriers to top level events occurring (i.e. measures to counteract hazards) are also included in the event trees.

2.3.4 Risk landscape model – Federal Office of Transport for Swiss Railways

Contact with the Federal Office of Transport for Swiss Railways, which is responsible for public transport policy in Switzerland, revealed that the risk landscape model is merely conceptual and has not been developed.

2.3.5 Irish Rail Safety Risk Model

The Irish Rail Safety and Risk Model combines a detailed, comprehensive assessment of rail risk with cost benefit analysis. The model aims to estimate risk levels at different locations on the rail network. The predictive risk model estimates risk for passengers, staff, members of the public and trespassers using fault and event tree analysis to identify accident precursors and possible outcomes.

2.3.6 Generic Error Modelling System (GEMS) (Spain)

The Generic Error Modelling System (GEMS) is based on James Reason's (1990) Skills, Rules and Knowledge Framework and Rasmussen's Step Ladder Model (1986) (as cited in Embrey, 2005). GEMS systematically examines human performance and recognises the shift between skill, rule and knowledge-based activities.

This model is used by the RU, Renfe, and its focus is on preventing and acting upon the causes that relate to human factors. The objective is to anticipate when and under what conditions a certain type of human error is likely to occur. Human error is categorised into slips and mistakes, and analysis of human performance allows potential errors to be identified and the risk of the hazard being realised combatted at source. Some of the errors included in the model are:

- Skill-based, e.g. inattention
- Rule-based, e.g. applying incorrect rule
- Knowledge-based, e.g. lack of understanding of systems, overconfidence, etc.

This is different to other models, for example the PIM, which consider a number of factors, including technical and environmental causes.

2.3.7 Safety Risk Model (SRM)

The Safety Risk Model (SRM) is a quantitative representation of the potential accidents resulting from the operation and maintenance of the rail network in Great Britain (GB). It comprises a total of 120 individual models, each representing a type of hazardous event. A hazardous event is defined as an event or an incident that has the potential to result in injuries or fatalities.

The SRM is, where possible, populated using data from the rail industry's safety related incident data taken from the safety management information system (SMIS). The SRM also includes predictions of the risk contribution from low frequency but potentially high consequence accidents for which there are little or no relevant data available. Where few data exists the model makes significant use of structured expert judgement from technical specialists to populate the model.

The results of the SRM are published in the Risk Profile Bulletin. The most recent version, version 7, was published in August 2011. Developed over a period of ten years, the SRM represents a mature model and forms the basis of the fault trees developed for this project.

2.3.8 London Underground Quantified Risk Assessment (LUQRA)

The London Underground Quantified Risk Assessment (LUQRA) model is based on the RSSB Safety Risk Model (SRM) in which a series of undesired top events are identified and fault paths displayed graphically on fault trees. The fault trees are populated with reliability and failure frequency data, where available, with supplementary estimates derived by industry experts and human error analysis. Twenty top events are modelled for each of the ten London Underground lines. It is important to note that, although the fault trees are the same for each line, due to variations in technology and environment, the frequencies and failure rates vary between lines.

London Underground shared their fault trees and all precursors appropriate to the six identified accident types were added to the accident precursor inventory, described below.

The Docklands Light Railway also has a Quantified Risk Assessment Model. The precursors within this model were reviewed but mirrored those identified by LU.

2.3.9 Korean Risk Assessment Models

The Korean Railroad Research Institute (KRRI) has been developing common risk assessment models since 2005. The risk assessment models are based on the following accident scenarios:

- Train collision incident
- Train derailment accident
- Train fire accident
- Level crossing accident
- Railway casualty accident (understood to be a person harmed on the railway as opposed to the train)

The accident scenarios were developed using fault tree analysis and then the frequency of each accident scenario evaluated using historical accident data and expert judgement. Event tree analysis was used to assess the severity of each hazardous event. The risk assessment models were used to review the Korea rail industry’s safety performance and assess it against some defined risk areas.

The risk models were further developed and combined with safety management to create a Railway Risk Assessment Information Management System (RAIMS). The purpose of RAIMS is to generate key risk assessment results for railway safety management.

Accident precursors and data used within the fault trees have not been published.

2.3.10 The Danish accident reporting system

The Danish NSA, Trafikstyrelsen, provided information on its accident reporting system for national RUs and IMs (personal communication, October 2012). In addition to reporting on the six accident precursors required by the CSI framework, Denmark has also instated a system where other events, labelled ‘safety irregularities’, are reported to the NSA, along with a detailed description, information on place and time, and information regarding the companies involved in the event. The safety irregularities that are monitored are:

- Risk of personal collision
- Brake malfunctions
- Irregularity in rail crossing
- Deformation of the tracks
- Errors in signalling
- Profile conditions
- Vandalism

- Other irregularities

Although IMs and RUs are obliged to provide detailed reports, they do not always provide a description of the incidents; sometimes the event is only classified according to one of the categories listed above.

2.3.11 Rail Accident Risk Model Conclusion

Information regarding specific accident precursors and associated fault trees was gathered from five of the nine known rail risk models. The four models where information was unavailable was due to the models being in the initial stages of development and not having data or fault trees to share at this stage. Where information was available, organisations were willing to share information. Identified accident precursors were added to the accident precursor inventory to ensure that the fault trees being constructed included all relevant precursors from across Europe.

2.4 Development of accident precursor inventory

The accident precursor inventory (API) was developed as a means of collating information in one place to ensure that the fault trees being developed included all appropriate precursors and fault paths identified in existing risk models, relevant literature and data sets. It allows the content of the risk models to be displayed clearly and compared simply. The API has been developed with a section for each of the six selected accident types:

- Derailment
- Collisions of trains
- Collisions with obstacles
- Level crossing accidents
- Fires in rolling stock
- Accidents to persons caused by rolling stock (excluding suicides)

Each section lists high level precursors for that accident type, any alternative terminology and references, as well as identifying which risk models include that particular precursor.

The API was used to verify that the fault trees being developed were comprehensive whilst remaining fit for purpose. The accident precursor inventory was developed further in Step 2 of the project to include additional terminology, any available data and information about who is currently gathering precursor information. This would allow all known accident precursors to be displayed in one table, reveal which accident precursors were included in existing risk models and identify the accident precursors that are currently being monitored by RUs, IMs and NSAs across Europe.

2.5 Accident databases

2.5.1 Terminology

Significant accidents are defined by the Railway Safety Directive, Commission Directive 2009/149/EC, and Regulation (EC) No 91/2003 on rail transport statistics (as cited in European Railway Agency, 2011); that is, any accident involving at least one rail vehicle in motion that causes:

- at least one person to die within 30 days of the accident, or to be seriously injured (hospitalised for a period of at least 24 hours) excluding attempted suicides, (regardless of whether they result in a fatality or serious injury),
- damage to stock, track, other installations or environment that is equivalent to €150,000 or more, or
- suspension of train services on a main railway line for six hours or more.

Accidents in workshops, depots and warehouses are excluded. A serious injury is classified as one in which a person remains in hospital for more than 24 hours.

Significant accidents are reported by NSAs in the Common Safety Indicators (CSIs).

Serious accidents are defined by the Railway Safety Directive as any train collision or derailment of trains, resulting in the death of at least one person or serious injuries to five or more persons or extensive damage to rolling stock, the infrastructure or the environment, and any other similar accident with an obvious impact on railway safety regulation or the management of safety; 'extensive damage' means damage that can immediately be assessed by the investigating body to cost at least €2 million in total (European Railway Agency, 2011).

Serious accidents are investigated by National Investigation Bodies (NIBs).

2.5.2 UIC Database

The UIC database collects information on significant accidents. In May 2012, there were 20 participating UIC European railway members as shown in Table 2.

Table 2: UIC Safety Database Members (May 2012)[5]

Country	Member
Austria	ÖBB
Belgium	Infrabel
Czech Republic	CD
France	SNCF
Germany	DB-Netz
Great Britain	Network Rail (RSSB)
GB/FR	Eurotunnel
Hungary	MAV
Italy	RFI
Luxembourg	CFL
Netherlands	ProRail
Norway	JBV
Poland	PKP PLK
Portugal	REFER
Romania	CFR S.A.
Slovak Republic	ZSR
Slovenia	SZ
Spain	ADIF
Sweden	TRAFIKVERKET
Switzerland	SBB/CFF/FFS

2.5.2.1 Accident types

In the three year period between July 2009 and June 2012, there were 6,296 accidents reported in the safety database, and the percentages of significant accident types reported to UIC were as shown in Table 3.

Table 3: UIC accidents (July 2009 – June 2012) disaggregated by accident type

Accident Type	Percentage
Derailments	10%
Collisions of trains	3%
Collisions with obstacles	11%
Level crossing accidents	39%
Fires in rolling stock	2%
Accidents to persons caused by rolling stock (excluding suicides)	35%

[5] http://safetydb.uic.org/spip.php?article4

2.5.2.2 *Accident causes*

The UIC provided information (type, event and cause) on those accidents which occurred in 2011. No details were provided of which UIC members reported the accidents, the accident locations or the parties involved. The data were analysed to provide a more detailed breakdown of accident causes which fed into the development and population of the fault trees described later in this report. Figure 4 shows a high level view of accident causation.

2011	Causes at first level	Causes at second level	
EXTERNAL CAUSES 78,2%	THIRD PARTIES 76,8%	Trespass (intrusion)	45,8%
		Vehicle (case of LC accident)	14,4%
		Pedestrian (case of LC accident)	8,4%
		Objects on the gauge	0,3%
		Vandalism	0,3%
		Other or not specified	7,6%
	WEATHER & ENVIRONMENT 1,4%	Environment	0,9%
		Weather	0,5%
		Not specified	0,0%
INTERNAL CAUSES 20,9%	RAILWAY SUB-SYSTEMS 5,9%	Rolling stock	3,2%
		Infrastructure (track & structures)	2,0%
		Energy system	0,4%
		Control-command signalling	0,2%
		Operations & traffic management	0,2%
	HUMAN FACTORS 15,0%	Passengers and freight company customers	8,3%
		Control-command, energy, traffic operating and switching staff	1,7%
		Traindriver and train crew	2,3%
		Track and track contractors staff	1,5%
		Other human factor in RUs	0,2%
		Other users	0,5%
		Not specified	0,6%
CAUSES NOT IDENTIFIED			0,9%

Figure 4: Causes of train accidents in 2011 (UIC Safety Database)

Almost half of the causes were classified as trespass, a cause which was outside of the scope of this project. In addition, a not unsubstantial proportion was classified as 'Other', 'Not specified' or 'Not identified'. It is also notable that 'human factors' are responsible for approximately two and a half times as many accidents for which 'railway sub-systems' are responsible. Many of the accidents classified as caused by a problem with railways sub-system are likely to involve human errors as well. Many of the other categories are collections of accident causes but do little to inform in terms of accident precursors as such.

2.5.3 ERAIL Database

The ERAIL database contains information on railway accidents in Europe, having collected information systematically since 2006. As shown in Figure 5, two datasets are available:

- The set of aggregated data on common safety indicators (CSIs), which contains the number of significant railway accidents, accident precursors and other safety indicators.
- The set of occurrences that have been investigated by National Investigation Bodies (NIBs).

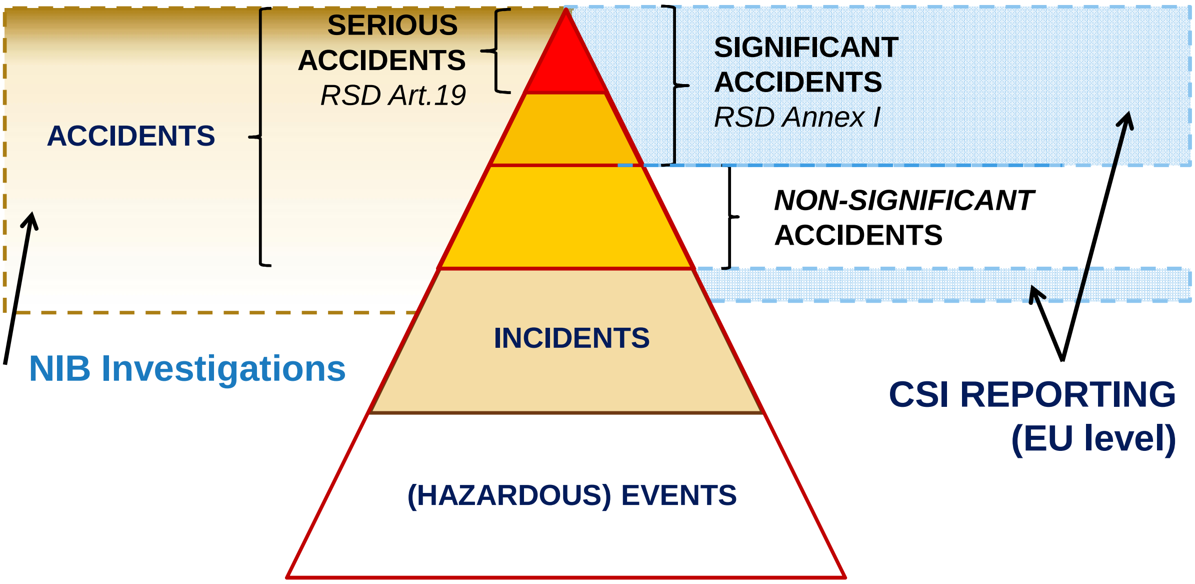


Figure 5: Scheme for mandatory railway accident monitoring at EU level (ERA, 2013)

The European Railway Agency (2011) presents some of the data from the ERAIL database, including the numbers of significant accidents for each accident type and the numbers of each of the six CSIs disaggregated by country and by year from 2007 until 2010.

2.5.3.1 Significant accidents (CSIs)

According to annual safety reports by the NSAs, there are approximately 3,000 significant accidents occurring in 27 European countries[6] each year. Based on the ERAIL database as at 12th October 2012, the number of accidents of each type and the percentage of accidents they represent for the five year period from 2007 to 2011 inclusive were as shown in Table 4.

Table 4: ERA average number of accidents per year (2007-2011)

Accident Type	Accidents per year
Derailments	208 (7%)
Collisions of trains	174 (6%)
Collisions with obstacles	222 (7%)
Level crossing accidents	843 (27%)
Fires in rolling stock	62 (2%)
Accidents to persons caused by rolling stock (excluding suicides)	1,580 (51%)

[6] All EU countries except for Malta and Cyprus are included; in addition, Norway and the Channel Tunnel are included.

This is broadly consistent with the UIC database, as shown in Table 3, with one substantial exception: accidents to persons caused by rolling stock are much more common in the ERAIL database than they are in the UIC database.

2.5.3.2 Precursors (CSIs)

Based on the ERAIL database as at 12th October 2012, the number of precursors and the percentage of precursors they represent for the same five year period were as shown in Table 5.

Table 5: **ERA average number of precursors per year (2007-2011)**

Precursor	Percentage
Broken rails	5,234 (41%)
Broken wheels or broken axles	162 (1%)
Track buckles	2,091 (17%)
Wrong side signalling failures	848 (7%)
Signals passed at danger	4,297 (34%)

2.5.3.3 Investigated occurrences

Since 2006, ERA has received reports of those rail accidents and incidents investigated by the National Investigation Bodies (NIBs) – normally around 200 a year – and this dataset is publicly available in the ERA ERAIL database. The majority of investigated occurrences are serious accidents investigated in accordance with Article 19(1) of the Railway Safety Directive.

Each occurrence is reported first as a 'notification' on starting a NIB investigation and later as a final report.

As of October 2012, this dataset contained 1,395 records, including 1,093 'final reports' and a further 392 'notifications'. This includes some incidents from years prior to 2006 which were removed from the analysis due to reporting not being standard at that time. This left a total of 1,349 records in the dataset. Figure 6 shows the number of reports included in the October 2012 dataset by year and report type (final report or notification).

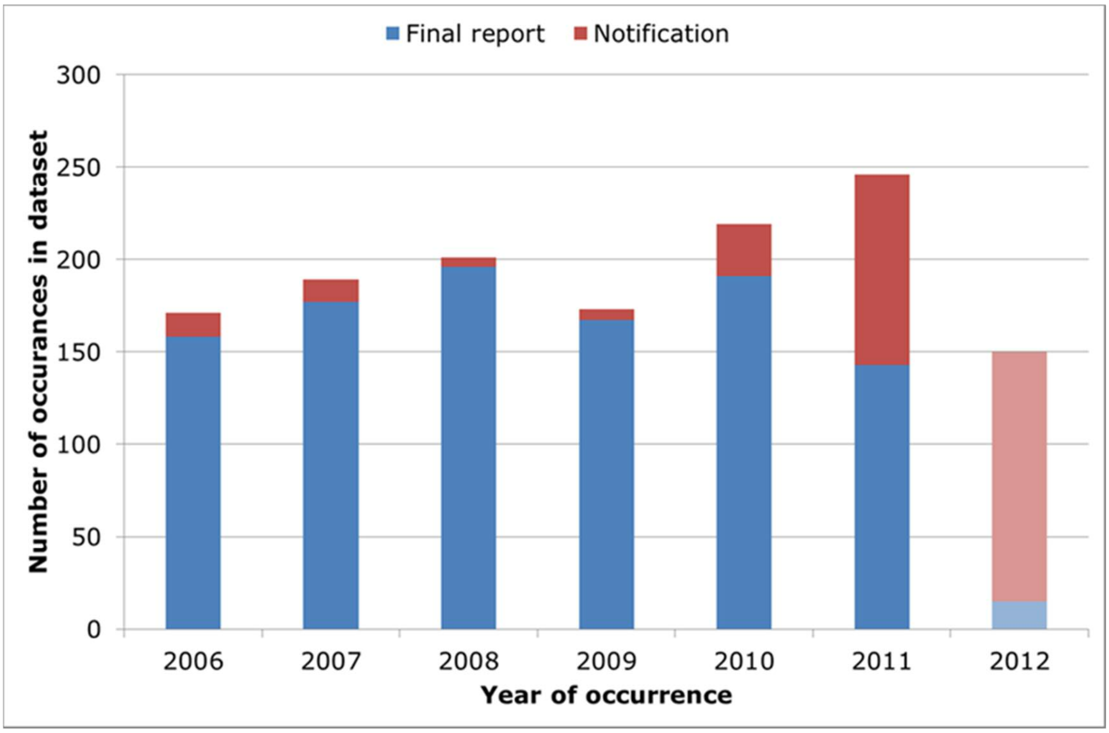


Figure 6: Reports included in October 2012 dataset (ERAIL, ERA)

Given the timing of the sample being obtained (October 2012), the 2012 data were obviously incomplete. In addition, a much higher proportion of 2011 records (than earlier years) were still at the notification stage and are likely to be converted to final reports at a later date.

Each record is categorised by an 'occurrence type', these normally being accident types or precursors (in the case of those incidents investigated that were not accidents). The numbers of incidents (final reports and notifications combined) split by occurrence and injury severity type for the period from 2006 to 2011 are shown in the following tables: Table 6 presents the accident numbers and Table 7 presents the near miss numbers. For example, there were eight reports for which the occurrence type was a broken wheel or axle.

Table 6: ERA accidents investigated by NIBs (2006-2011) disaggregated by occurrence type and severity

Occurrence type	Serious*	Significant
Derailments	14	314
Collisions of trains	26	100
Collisions with obstacles	12	82
Level crossing accidents	208	290
Fires in rolling stock	2	46
Accidents to persons caused by rolling stock (excluding suicides)	152	180

* Classified as serious on the basis of injury severity only – excludes those which would be classified as serious only on the basis of extensive damage caused and/or suspension of service

Table 7: ERA incidents investigated by NIBs (2006-2011) disaggregated by type

Occurrence type	Incidents
Broken rails	5
Broken wheels or axles	8
Track buckles	2
Wrong side signalling failures	9
Signals passed at danger (SPADs)	56
Dangerous goods releases	1
Unauthorised train movements other than SPADs	1

In addition, there were 105 occurrences classified as 'Other'. Three of these were serious accidents; it is not clear which of the other 102 were accidents and which, if any, were near misses.

Table 6 shows that derailments and level crossing accidents are the most common occurrence types investigated by the NIBs and reported to ERA, followed by accidents to persons caused by rolling stock in motion. Fires in rolling stock are the least frequent accident type that are investigated and reported to ERA. It is notable that the number of accidents to persons caused by rolling stock in motion is the most common accident type by some margin – see Table 4 - but are only the third most commonly investigated.

Table 6 also shows that Signals Passed At Danger (SPADs) are the most common precursor type that are investigated and reported to ERA; there are very few incidents involving other precursors that are investigated and reported to ERA. This is, perhaps, surprising given the findings presented in Table 5: broken rails are a more frequently reported precursor than SPADs are. There are a substantial number of near-misses with the occurrence type 'Other' that are investigated and reported to ERA. These may warrant further analysis to be classified more fully.

2.5.3.4 Accident causes

ERA provided a limited extract from the database to TRL for this study containing more information about many of the occurrences. For this project, TRL investigated two particular fields from this extra information: 'underlying causes' and 'direct and immediate causes'. These two fields are free text fields, making them difficult to analyse systematically. These were available only for some final reports. However, investigating the occurrence types of the records that have reported causes is informative.

Just over a third of the 'final report' records from 2006-2011 have 'underlying causes' reported, and these records come from 12 of the 18 occurrence types: the accident types and precursors, plus an 'other' category. More than half of the 'final report' records have 'direct and immediate causes' reported, these falling into the same 12 occurrence types. Table 8 shows the 355 incidents with underlying causes and the 551 incidents with direct and immediate causes disaggregated by occurrence type, and as proportions of the number of final reports of each type recorded by the ERA. For example, 124 derailment occurrences had underlying causes recorded, this representing 46% of the total number of derailment occurrences.

Table 8: Number and percentage of occurrences investigated by NIBs with 'underlying causes' and 'direct and immediate causes' by type of occurrence

Occurrence type	Underlying causes	Direct and immediate causes
Derailments	124 (46%)	173 (65%)
Collisions of trains	38 (43%)	53 (60%)
Collisions with obstacles	32 (44%)	40 (65%)
Level crossing accidents	52 (21%)	101 (41%)
Fires in rolling stock	13 (31%)	25 (60%)
Accident to persons caused by rolling stock (excluding suicides)	26 (16%)	57 (36%)
Broken rails	3 (100%)	3 (100%)
Broken wheels or axles	2 (33%)	6 (100%)
Track buckles	2 (100%)	2 (100%)
Wrong side signalling failures	4 (50%)	3 (38%)
Signals passed at danger (SPADs)	7 (15%)	28 (60%)
Other	52 (60%)	60 (70%)
Total	**355 (34%)**	**551 (53%)**

Table 6 showed that derailments are the most common occurrence type investigated and this is reflected to some extent in the numbers of those that have underlying causes or direct and immediate causes recorded. However, a smaller proportion of the second most common occurrence type investigated, 'level crossing accidents', and also 'accidents to persons caused by rolling stock' have causes recorded than other accident types.

2.5.3.5 Free text cause descriptions – train collisions

Those 38 accidents classified as 'collisions of trains' with 'underlying causes' or 'direct and immediate causes' were selected for further analysis to see whether the free text descriptions could be used to identify further relevant causal factors. (A more comprehensive ERAIL taxonomy has been introduced into ERAIL database only recently, so running a query was not the option in this case.)

TRL identified ten common causal factors from this subset with some accidents having more than one identified causal factor. Independently, ERA also analysed the free text descriptions for the same set of accidents, and identified causal factors for 32 of the 38 accidents, identifying eight common causal factors. However, the causal factors identified by the two parties were different and the frequencies with which common causal factors were identified were also different, as shown in Table 9.

Table 9: Causal factors for train collisions identified from free text

TRL-identified causal factor	Percentage	ERA identified causal factor	Percentage
Train driver error	34%	Signals passed at danger	21%
Operational staff / signaller error	24%	Entering occupied track	11%
Miscommunication	18%	Departures without permission	8%
Runaway	8%	Overspeeding	8%
Track fault	8%	Late braking	8%
Other human staff error	8%	Signal failures	8%
Environment	5%	Points failures	5%
Rolling stock fault	5%	Runaway	5%
Signals passed at danger	3%		
Loading error	3%	Uncategorised	26%

Note that the TRL-identified causal factors sum to more than 100% because some accidents were assigned more than one causal factor.

The correlation between the two sets of categorisations was investigated and emphasised the differences: for example, fifty per cent of the accidents identified by ERA as 'signals passed at danger' were categorised as 'driver errors' by TRL.

The differences in the categorisations between the two analyses suggest that this is not a reliable approach that would present consistent results: two different people created categories and classified accidents in different ways, both of which were entirely reasonable, but got very different results.

One possible way of reducing such inconsistencies in the future and making the dataset easier to use would be to develop the 'taxonomy of accident causes' and use it when new occurrences are input into the database.

Using the TRL-identified causal factors, the identification of appropriate search terms for each causal factor was attempted, so that a text search could be employed in an efficient manner to identify causal factor for accident types other than collisions of trains. For example, it was suggested that the term 'signal' might identify those accidents in which 'signaller error' was the cause. However, this approach identified many accidents which were not associated with the cause concerned (in this case, 'signaller error'), and failed to identify many accidents that were associated with the causal factor concerned. This suggests that there is not a systematic way to identify causes from the free text descriptions without reading these in full.

2.5.3.6 Variation by country and by time

The numbers of occurrences with causes recorded, disaggregated by country and by year, were also briefly investigated. 22 countries have final reports with direct and immediate causes recorded in the dataset, though most countries have few recorded. The reporting rate pertaining to each country may vary over time: changes in the number of occurrences investigated by NIBs and reported to ERA may be a reflection of the NIB's capacity to investigate, the seriousness of accidents and other issues rather than the underlying safety, for example.

This preliminary analysis reveals substantial variation in the amount of information reported to ERA by different countries. This may partly reflect differences in accident numbers in different countries, but is also likely to reflect different railway network structures and on different approaches to reporting. It also suggests that the current ERA database might be improved by distinguishing better between causes, precursor types and accident types.

2.6 Fault tree development and population

It was essential to construct fault trees that were applicable to Europe and based on the theoretical knowledge gained in Step 1. In addition to identifying accident precursors for the identified accident types, information on risk modelling techniques within the rail industry and other industries was used to determine an appropriate method by which to display the fault trees and to establish best practice when populating fault trees with data. Fault trees and the associated modelling theory detailed in BSEN 50129:2003 (railway applications – communication, signalling and processing systems – safety related electronic systems for signalling) and the fault trees constructed for the European project 'Study on freight train derailments' (Det Norske Veritas, 2011) led the initial thinking into the fault tree construction.

Accident precursors identified in the literature review and information available from the researched rail risk models were used to construct the fault trees of the six accident types. Consideration was given to separating the fault trees for each accident type into two separate trees, one for freight trains and one for passenger trains. For derailment accidents, this split was made; however, the differences[7] were not substantial for other accident types and so passenger and freight train accidents were combined: although they may have different severity outcomes, freight and passenger train accidents tend to have similar causal factors, derailment accidents aside.

The fault trees developed are shown in Appendix B in a traditional graphical format. The precursors are colour-coded with red representing a larger contribution to risk and green a smaller contribution to risk at the level above. This colouring is based on the data made available to the project team, from existing rail risk models and rail accident databases as described above, combined using the expert judgement available within the project team.

The data available to populate the fault trees included accident data from ERA and UIC, as described in section 2.5, and precursor information from European models made available in confidence to inform this project. Where classifications of accident causes and precursors could be directly mapped onto the classifications used in the fault trees, for example, European data

[7] For train - train collisions, the collision could be passenger train – passenger train, passenger train – freight train, or freight train – freight train. For a same speed collision, one would expect that passenger train - passenger train would have the highest consequences and the freight train - freight train the lowest consequences.

The frequency of a runaway leading to a collision, although small, is a factor of ten higher for freight trains than passenger trains.

Collisions with objects and level crossing collisions have all the same causes, but the consequences might be lower for freight trains.

A number of the causes of fire are specific to passenger trains, for example interior fires and some are specific to freight, for example cargo fires.

Train movement injuries - most injuries on train will be people on passenger trains. Freight trains are more likely to have out of gauge objects.

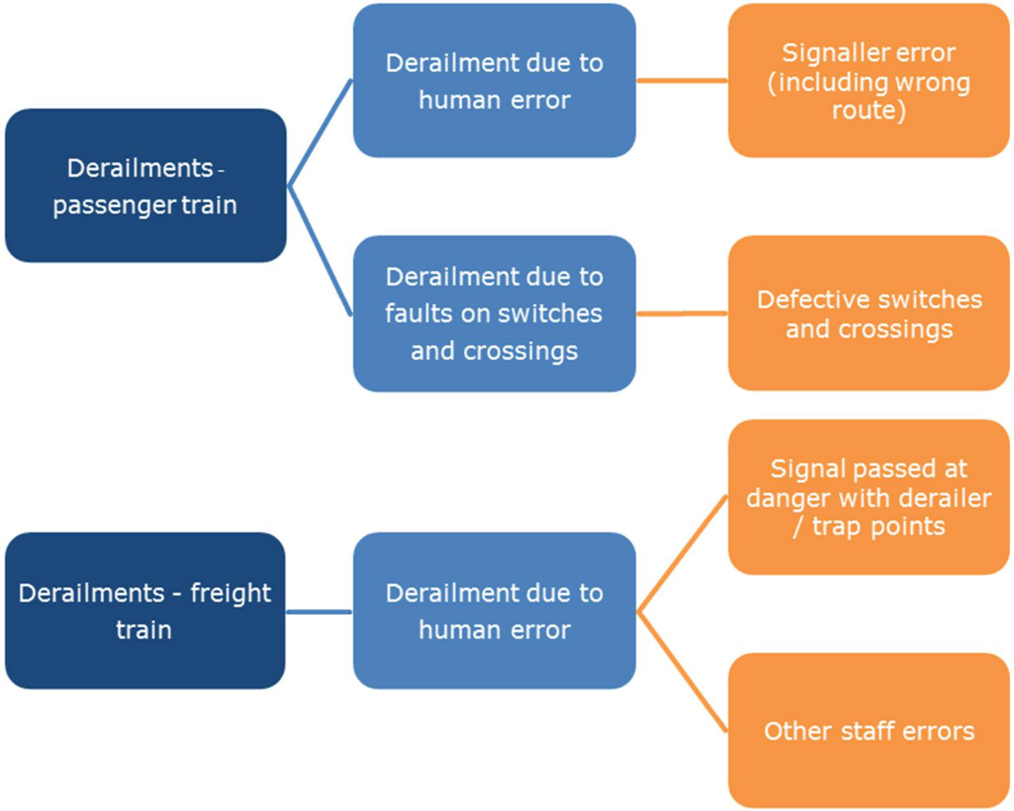
from ERA and UIC were used. Where data were limited or could not be directly mapped, the available data from existing European models were applied.

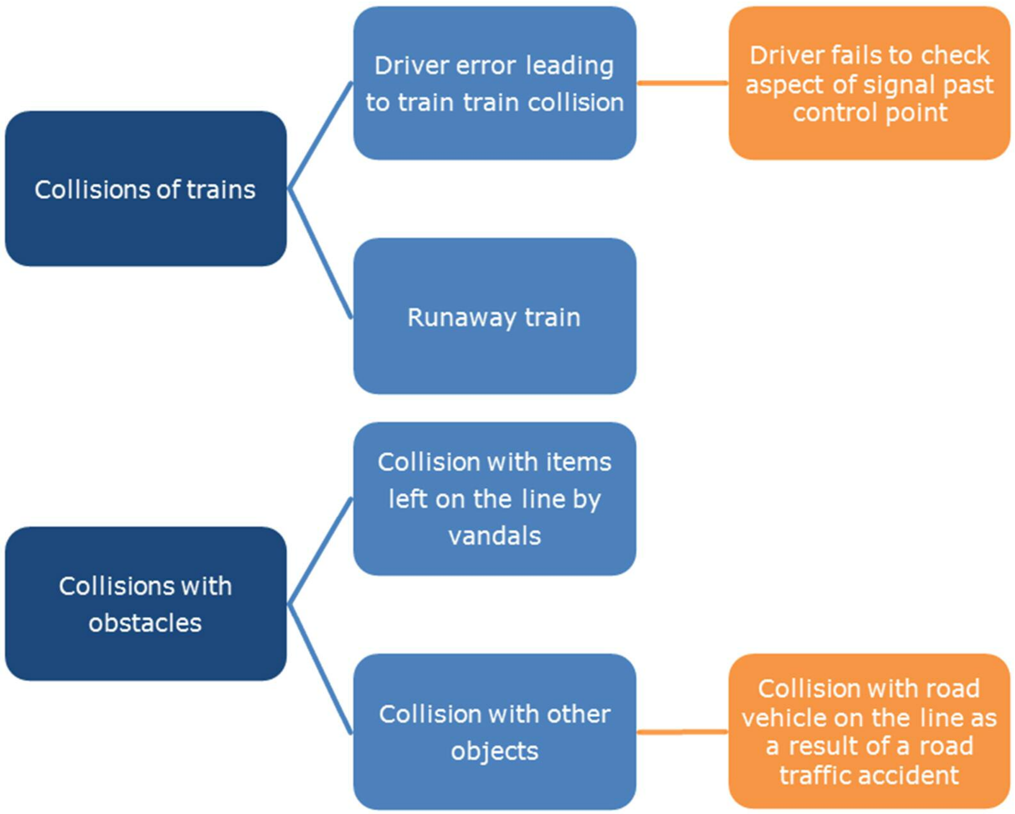
It should be noted that the results are intended to represent averages, rather than to be specific to any particular rail network. Populating the trees with country or network specific data would result in more meaningful figures given there are likely to be substantial differences between different countries and / or parts of the network. While the colour-coding should be considered as indicative only, providing exact figures at this stage is therefore likely to be misleading. The colour-coding allows overall probability ranking to be conducted and European priorities determined without breaching data confidentiality. A consistent approach to the recording of the causes of rail accidents and the use of precursors across Europe could enable accurate population of fault trees that are specific to any given network, and a transparent and robust set of results that enable a proactive approach to be taken to European-wide railway safety management.

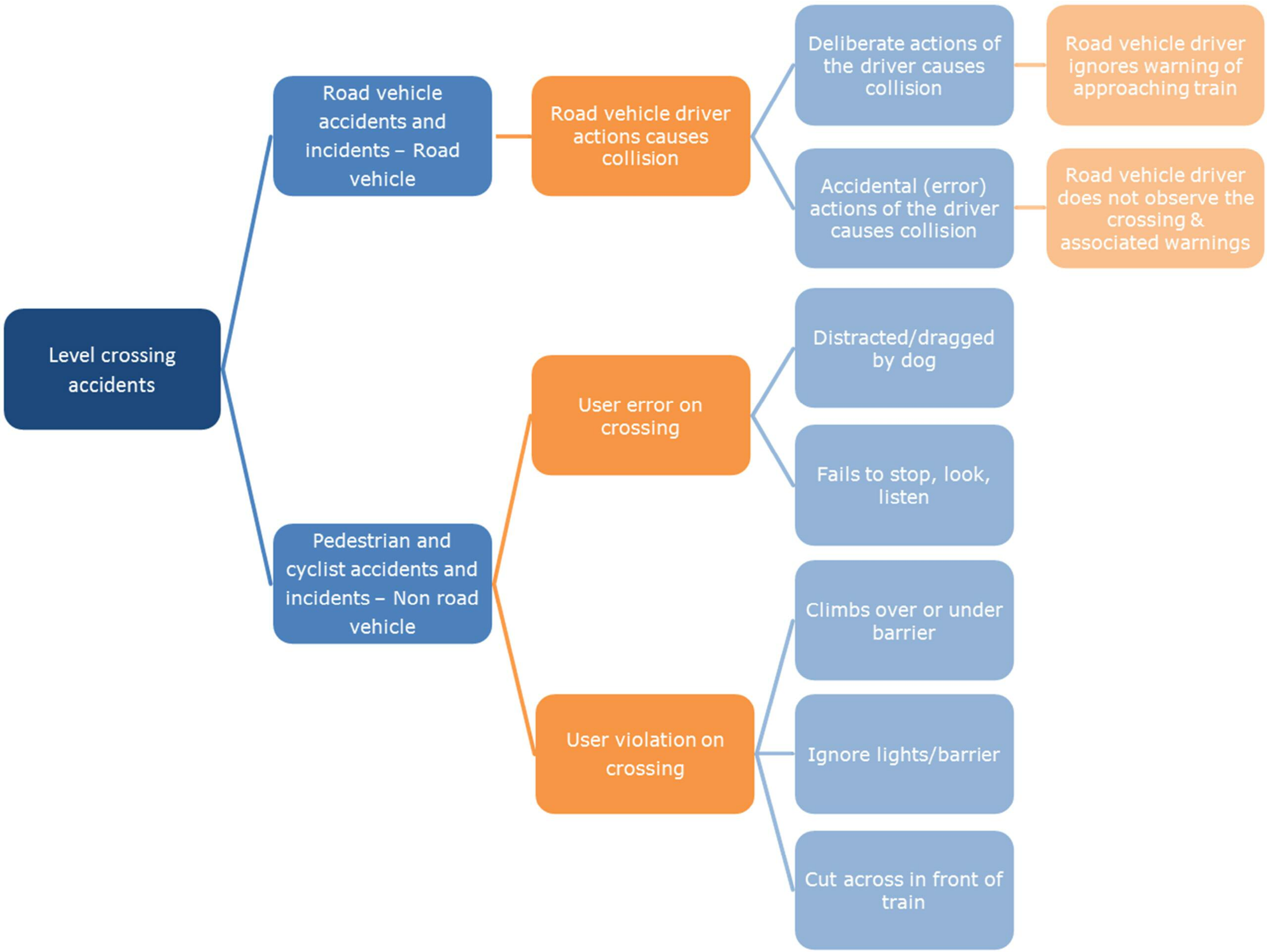
2.7 Priority precursors from Step 1

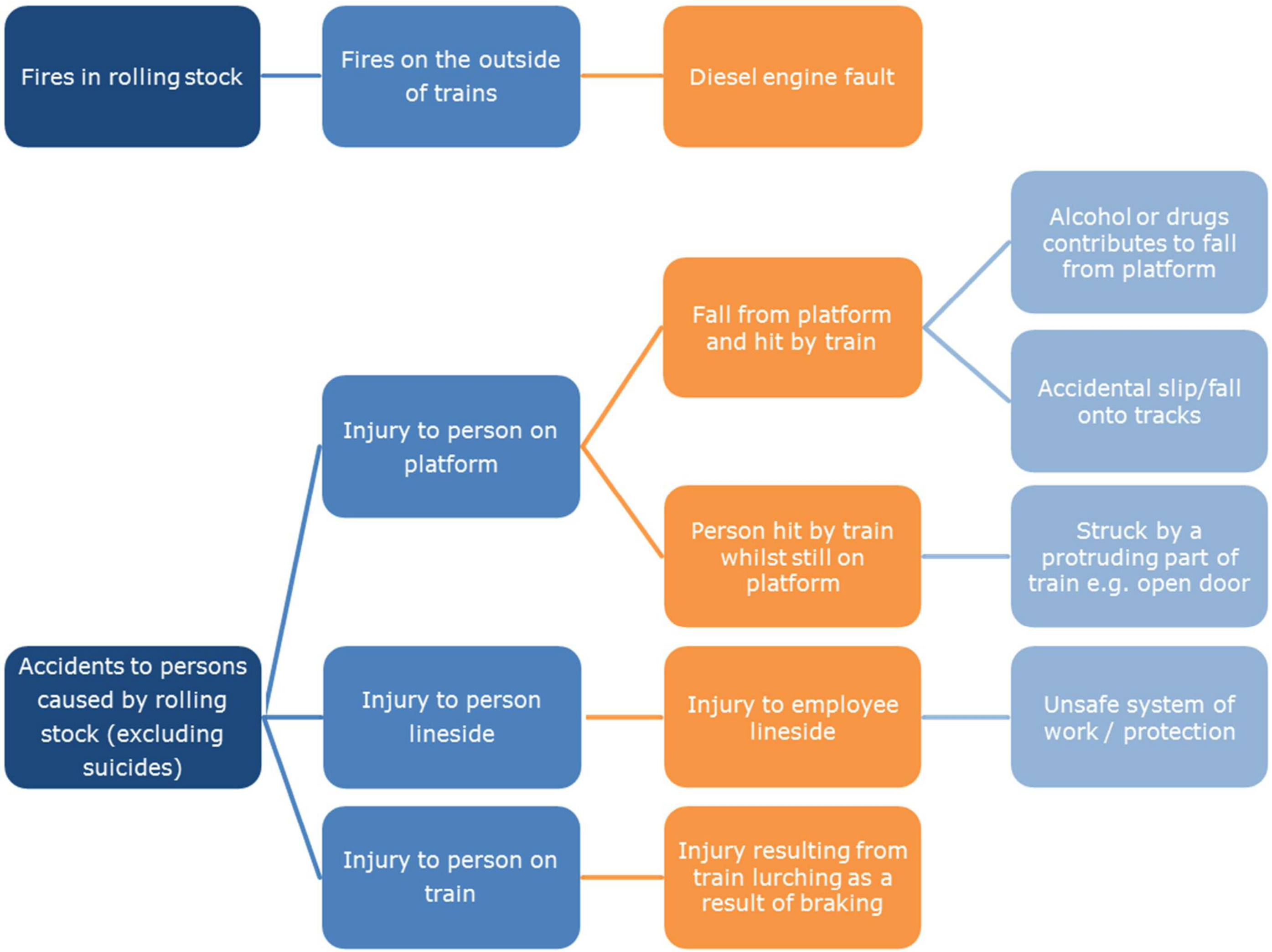
The fault trees indicate that there are 13 top level precursors which cause more than 20% of the risk associated with the accident type concerned. Below most of these precursors, there are many lower level precursors that contribute to more than 20% of the accident-related risk of the higher level precursor concerned. The priority precursors selected by taking this approach for each accident type are identified in a tree format in Figure 7, and in a tabular format in Appendix C. Were precursors to be recommended on the basis of theoretical risk alone, these would be the precursors recommended.

Figure 7: Step 1 Priority Precursors




Collisions of trains
Driver error leading to train train collision
Driver fails to check aspect of signal past control point
Runaway train
Collisions with obstacles
Collision with items left on the line by vandals
Collision with other objects
Collision with road vehicle on the line as a result of a road traffic accident


Level crossing accidents
Road vehicle accidents and incidents – Road vehicle
Road vehicle driver actions causes collision
Deliberate actions of the driver causes collision
Road vehicle driver ignores warning of approaching train
Accidental (error) actions of the driver causes collision
Road vehicle driver does not observe the crossing & associated warnings
Pedestrian and cyclist accidents and incidents – Non road vehicle
User error on crossing
Distracted/dragged by dog
Fails to stop, look, listen
User violation on crossing
Climbs over or under barrier
Ignore lights/barrier
Cut across in front of train


Fires in rolling stock
Fires on the outside of trains
Diesel engine fault
Alcohol or drugs contributes to fall from platform
Fall from platform and hit by train
Accidental slip/fall onto tracks
Injury to person on platform
Person hit by train whilst still on platform
Struck by a protruding part of train e.g. open door
Accidents to persons caused by rolling stock (excluding suicides)
Injury to person lineside
Injury to employee lineside
Unsafe system of work / protection
Injury to person on train
Injury resulting from train lurching as a result of braking

3 Step 2: Insight into current practice

For this second step of the study, detailed information was sought from NSAs, RUs and IMs regarding the monitoring, analysis and reporting of indicators relating to precursors of accidents.

3.1 Approach

Figure 8 outlines the approach for Step 2 of the study. Precursor data were sought from two sources: NSAs (to capture monitoring at the national level) and RUs/IMs (to capture monitoring at the level of individual operators). Both streams of data capture used questionnaires. The questionnaire for NSAs was prepared, administered and analysed by ERA, in consultation with TRL; the questionnaire for RUs and IMs was prepared, administered and analysed by TRL, in consultation with ERA, with the majority of information being provided by follow-up interviews and email exchanges with individual operators. All data sources were used to update the list of precursors in the inventory of accident precursors.

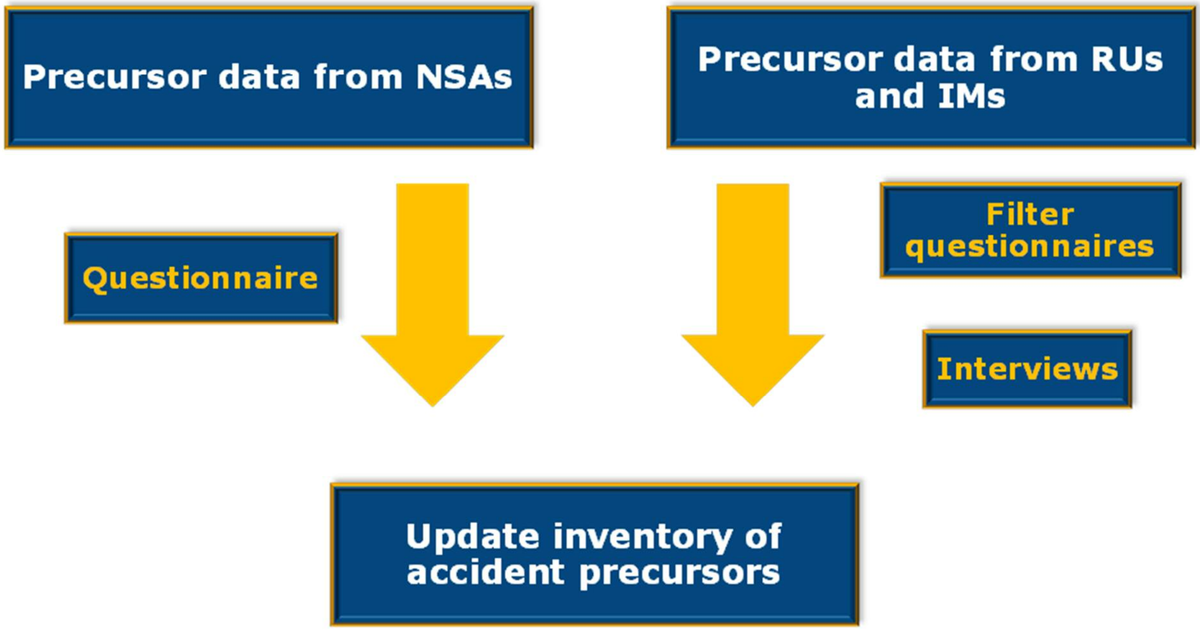


Figure 8: Overview of method for Step 2

3.1.1 Approach: precursor information from NSAs

TRL collaborated with ERA on the development of a questionnaire ERA then sent to NSAs. The questionnaire was designed to gather information on:

- Accident indicators and definitions that are supplementary to those specified in the CSI framework.
- Indicators related to accident precursors that are supplementary to those specified in the CSI framework, and their definitions.
- Reporting methods and structures for both indicators of accidents and of precursors to accidents.
- Provision and management of a national database to record indicators of accident precursors.

- Analysis and reporting of indicators of accident precursors at member state level.

ERA issued the questionnaire by email to the NSA Network, and provided all responses to TRL in a spreadsheet. ERA has subsequently produced a report of the findings (Eksler, 2013). It was initially envisaged that some comparisons could be made between the precursors that NSAs required RUs and IMs to report, and the precursors that were reported as being monitored by RUs and IMs in the sample. However, in some cases, the descriptions and definitions used by NSAs and RUs/IMs could not be compared due to differences in translation from the original member state language. In addition, a full list of precursors could not be compiled because some of the RUs and IMs in the sample were unable or unwilling to provide a complete list of precursors, for example, where they monitored a high number of precursors. Furthermore, for only three of the 12 countries sampled were responses received from both an RU and an IM, therefore providing limited opportunities to conduct a complete comparison between NSA and RU/IM precursors.

A limited comparison was done using data from the three countries for which both an RU and IM was interviewed: Bulgaria, Austria, and Italy. Table 10 provides details on the total number of precursors provided by NSAs, RUs/IMs from each of these countries. Italian RUs were overrepresented in the sample, as is discussed later, so many of the Italian precursors obtained appear to be duplicates. In addition, some of the incidents mentioned are not precursors in the sense of the word used in this study (e.g. 'killed animals' in Bulgaria, and 'number of requests for assistance' in Italy).

Table 10: Comparison of precursors reported in NSA vs. RU/IM surveys

Country	Level	No. of precursors provided	No. of precursors reported by both the NSA & RU/IM
Bulgaria	NSA	8	3
	RU/IM	16	
Austria	NSA	8	6
	RU/IM	74	
Italy	NSA	21	12
	RU/IM	161	

Although the limited sample precludes reaching any significant conclusions, the main differences between what NSAs reported and the information obtained from RUs/IMs appears to be in the level of detail. For example, the NSAs from Italy and Austria presented general categories of precursors (e.g. 'impairment of a safe operation through serious defects in technical equipment and rolling stock'), and compliance (e.g. 'loading conformity', 'driver behaviour conformity'). On the other hand, RUs and IMs tended to provide a more detailed set of precursors, such as faulty door locks (rolling stock faults), and overspeeding (driver behaviour).

As illustrated in Table 10, there is some discrepancy between the precursors reported by NSAs in the survey, and those obtained from RUs/IMs through Step 2. As mentioned previously, this difference could be due to the differences in translation. Alternatively, it may be a result of the fact that NSAs responded to a written questionnaire with little opportunity for clarification, whereas RUs/IMs were interviewed by telephone enabling much more detailed information to be obtained from the relevant parties.

Information on precursors monitored by NSAs was also used for this study, to contribute to the accident precursor inventory. The list of precursors reported by NSAs was reviewed and subjected to a filtering process in order to:

- Remove precursors that were equivalent to 'top events' (i.e. accidents)
- Remove items that did not qualify as a 'precursor' for this study (e.g. precursors related to suicides, precursors to accidents other than the six types selected for this study)
- Remove precursors that were already specified within the CSI framework

3.1.2 Approach: precursor information from RUs and IMs

The first stage of selecting a sample of RUs and IMs from which to gather detailed information about precursors was to develop an initial 'filter' questionnaire (Appendix D). This questionnaire was designed to be issued to all RUs and IMs for which contact details could be obtained. It collected basic information on:

- Monitoring and use of indicators relating to accident precursors.
- Development of safety/risk models that include precursor data.
- Development of fault/causal trees.
- Contact details for a relevant representative at the RU/IM.

Contact details for RUs and IMs were requested in an email sent to all NSAs in the network by ERA. In addition, details were sought for some RUs and IMs from stakeholder engagement. These processes did not yield sufficient contact details so further details were obtained by contacting different NSA representatives utilising the NSA Network.

Contact details were received for 103 RUs and 28 IMs across 19 European member states. Filter questionnaires were distributed by email to each RU and IM for which contact details had been provided.

The next stage was to select a sub-sample of RUs and IMs that was as representative as possible from those that completed the filter questionnaire and indicated that they collected precursor data in some form. Representativeness was assessed using the available characteristics of the sample and input from ERA. The characteristics that were considered included:

- Type of operator (a minimum of five IMs and five RUs each from different member states was required)
- Geographical location (to cover different areas of the European network)
- Network size of the member state (based on track km)
- Market size of the member state (to cover states with just a few RUs/IMs to those with multiple RUs and IMs)

A total of 19 organisations (13 RUs and 6 IMs) across 10 member states (plus Switzerland) were selected for further interviews, of which 10 were conducted by telephone and nine by email correspondence.

A detailed set of questions was put to each RU and IM. The questions were drafted in a topic guide (Appendix E) to ensure a consistent approach was used. Prior to the discussion, RUs and IMs that were selected to take part were sent an outline of the items to be discussed so that they could prepare adequately for the conversation and consult internally if necessary. Foreign language assistance was offered on request and was used for one of the telephone interviews[8].

For each indicator related to an accident precursor, respondents were asked to provide the following information for that precursor:

- Name and definition
- Associated accident types (i.e. for which accidents is the indicator a precursor)
- Purpose of monitoring
- Frequency of occurrence
- Frequency and style of reporting
- Reliability and quality

These data were collated into a table for each respondent. For the telephone interviews, at least one example of a precursor was discussed by telephone to ensure that the correct information was provided by the respondent. Respondents then had the option to either continue to provide the information by telephone for all the other precursors they monitored, or to receive a copy of the table by email to input the information electronically and then return it to the project team.

In addition to providing information about each precursor, respondents were asked to share any data or models they had that included accident precursors. This was supplemented by further discussion of the following items:

- Reasons for monitoring accident precursors
- Procedures for assessing the contribution of a precursor event to an accident
- Suggestions for European-wide monitoring of accident precursors
- Difficulties associated with monitoring accident precursors
- Suggested improvements to precursor monitoring
- Views on the indicators related to accident precursors that must be monitored within the European CSI framework

The content of the questionnaire and the approach were discussed with ERA throughout and regularly agreed with ERA, as required by the project specification; the questionnaire can be found in Appendix E.

3.2 Findings

This section outlines the findings from Step 2. It summarises the precursors collected by RUs and IMs but does not list each individual precursor that was identified during the process (although each unique precursor was considered for inclusion in the accident precursor inventory). It also summarises the operational experiences, difficulties, and suggested improvements that RUs and IMs associated with monitoring precursors.

[8] One of the interviews was conducted in Spanish. Another interview was conducted with simultaneous translation provided by the respondent. Email correspondence was sometimes provided in languages other than English so this was translated where appropriate.

3.2.1 Sample characteristics

This sub-section defines the sample of RUs and IMs that responded to the questionnaire and consultation.

3.2.1.1 Initial sample

Of the 131 RUs and IMs for which contact details were obtained, 46 (35%) provided a response to the initial filter questionnaire. The sample comprised 34 RUs, 10 IMs and two respondents that represented both RUs and IMs. The respondents represented 17 countries (15 member states plus Switzerland and Norway)[9]. Of these 46 respondents:

- 43 (93%) reported that precursors were monitored in their organisation
- 42 (91%) reported that precursors were also used by their organisation in some way
- 30 (65%) reported having a safety model[10] that included precursors
- 20 (43%) reported developing fault trees that included precursors

In summary, all of the 17 countries represented by respondents were found to have at least one RU or IM that monitored and used precursors in its operations.

3.2.1.2 Final sample

The final sample of operators selected for interview and further consultation comprised 13 RUs and six IMs (of which two represented RUs as well) across 12 different countries (11 member states and Switzerland). Table 11 provides sample characteristics for the 19 selected RUs and IMs, ordered within each category by the proportion of rail traffic in the corresponding country that they represent. All respondents except one were national operators and five of the selected RUs had cross-border operations. The sample represented a wide range of different operator sizes when comparing the number of staff and scope of operations. In particular, the RUs manage approximately 40% of rail traffic in Europe and the IMs manage approximately 25% of rail traffic in Europe.

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[9]. The following member states were represented in the sample: BG, ES, DE, PT, NL, DK, AT, LV, IT, and HU. RUs and IMs in the UK were not included as sufficient information on precursor monitoring in Great Britain was supplied by RSSB and by one RU that was visited as part of Step 1.

[10] A 'safety model' can refer to any quantitative representation of the potential for an accident to occur as a result of the operation and maintenance of all or part of a railway network. A safety model may include models that quantify the relationship between precursors and accidents, or other hazardous events that have the potential to cause damage or harm.

Table 11: Sample characteristics of RUs/IMs selected for interview and consultation

RU/IM	MS	Cross-border operations	Staff	Million train km (pax/freight/both)	Million pax km	Freight carried million tonne per km)	Line km	Track km
RU/IM	DE	Yes	180,000**	- / - / 758	79,200	106,000	33,576	61,745
RU/IM	CH	-	-	- / - / 165	17	12	3000	-
RU	LV	No	11,665	6 / 12 / 18	733	21,410	N/A	N/A
RU	ES	No	14,000	162 / 23 / 185	-	500	N/A	N/A
RU	FI	No	11,000	- / - / 50	4,000	-	N/A	N/A
RU	IT	Yes	37,660	247 / 29 / 276	39,000	12,800	N/A	N/A
RU	NL	-	13,000	- / - / 115	15,700	-	N/A	N/A
RU	LV	Yes	2,637	- / 12.6 / 12.6	-	16,551	-	-
RU	DK	Yes	10,000	58 / - / 58	6,000	-	N/A	N/A
RU	PT	No	2,957	- / - / 29	3.75	-	-	-
RU	BG	Yes	6,200	- / - / 20	1,950	-	N/A	N/A
RU	IT	No	1,200	2.2 / - / 2.2	529	-	-	-
RU	IT*	No	150	- / - / 2.2	0.9	-	N/A	N/A
RU	IT	No	-	- / 0.7 / 0.7	N/A	230	-	755
RU	AT	-	-	-	N/A	-	N/A	N/A
IM	BG	No	10,000	23 / 7 / 30	5,630	7,751	6,638	8,126
IM	AT	No	16,903	- / - / 144	-	-	4,835	-
IM	IT	No	900	- / - / 9.3	1,400	0.006	-	500
IM	HU	No	2,200	-	220	4.8	424	-

* This operator is a regional operator only ** 285 members of staff are located centrally

The characteristics of the 12 countries represented by the sample were also diverse (Table 12). The market sizes ranged from highly competitive markets with multiple RUs and IMs to markets where there were single operators and little competition. Network sizes (un terms of line kilometres) ranged from 2,000 km to 63,000 km, and the traffic levels ranged from 18 million train km per year to over a billion train km per year. Different regions of Europe were also well-represented, with Southern and Eastern Europe each represented by three RUs/IMs, Northern Europe represented by two RUs/IMs and Western Europe represented by four RUs/IMs.

Table 12: Sample characteristics of countries represented in interviews and consultation

Member state	Market size		Network size (1,000km)*	Train km (million)*	Geographical location
	No. of IMs	No. of RUs			
DE	180	400	63.1	1063	Western Europe
IT	1	32	24.4	317	Southern Europe
ES	2	11	19.4	191	Southern Europe
HU	2	34	13.1	97	Central Europe
FI	1	1	8.9	51	Northern Europe
AT	12	53	7.2	152	Central Europe
NL	2	31	7	161	Western Europe
BG	1	11	5.2	31	Eastern Europe
CH	4	58	5.1	-	Western Europe
DK	9	16	4.1	85	Northern Europe
PT	1	4	3.5	37	Southern Europe
LV	1	5	2.3	18	Eastern Europe

*Source: ERA CSI reports, 2011

Overall, the characteristics of the sample were assurance that the diversity of European operators would be represented in the study.

3.2.2 Precursor monitoring by NSAs

All NSAs responded to the questionnaire that they received from ERA. Overall, the NSAs for six member states (DE, ES, LU, NO, RO, SK) did not collect any precursors at a national level in addition to those six that are specified in the CSI framework.

Across all of the NSAs that did collect further precursors, there were approximately 250 additional items, of which approximately 170 were put forward to be assessed for inclusion in the accident precursor inventory. The remaining precursors were excluded according to the process highlighted in section 3.1.

3.2.3 Precursor monitoring by RUs/IMs

As reported in section 3.2.1.1, 95% of the RUs and IMs that responded to the initial questionnaire monitored precursors. Interviews and email consultations provided further information on the extent of precursor monitoring by a sub-sample of 19 RUs and IMs. This ranged from the collection of no precursors other than those specified in the CSI framework (an RU in Austria) to approximately 1,500 precursors collected by an IM in Austria, as shown in Table 13. It was more common to collect up to 10 additional precursors (as reported by 10 respondents), with the remaining six respondents collecting between 12 and 133 additional precursors.

With a small sample, it is not possible to draw conclusions about European trends in the data. However, there was no marked difference between RUs and IMs with regard to the number of precursors collected (with the exception of the IM in Austria). It was also noted that Italian

RUs had more extensive precursor monitoring (ranging from 9–133 precursors), although Italian RUs were generally over-represented in the sample. Nevertheless, there was evidence from Step 2 that Italian RUs had developed comprehensive safety models that utilised a wide range of precursors when compared with a number of the other respondents.

It is worth noting that RUs and IMs in the current sample appeared to have different interpretations of the term 'precursor'. This issue is briefly discussed in a later section.

Table 13: Number of additional precursors monitored by RUs/IMs

RU/IM	MS	No. of non-CSI precursors monitored	Description
IM	AT	1,500	Multiple levels within fault trees capture a wide range of incidents and root causes, which creates a substantial number of precursors in total.
RU	IT	133	Classified as 'dangerous events' (the higher of two levels of precursors). 472 further precursors are classified as 'primary causes' (the lower of the two levels monitored).
RU	IT	71	
RU	IT	23	
RU	LV	15	
RU	IT	13	
RU/IM	DE	12	Further lower level precursors are monitored by smaller operations within the company but 12 are monitored centrally.
RU	LV	10	
RU	NL	9	
IM	BG	9	
IM	IT	9	
RU/IM	CH	8	
RU	ES	8	
RU	BG	7	
RU	FI	6	
RU	DK	5	One of the 5 precursors is SPADs, which has 7 sub-categories; another is fires in rolling stock, which has 3 sub-categories.
IM	HU	1	
RU	PT	Multiple	Collect data on incidents other than the 6 CSI precursors but do not classify them as 'precursors'.
RU	AT	-	This RU monitors only the precursors specified in the CSI framework.

3.2.4 Precursor reporting

The frequency with which RUs and IMs had to report precursors to NSAs ranged from weekly to annually. For example:

- A Dutch RU reported precursors to the NSA weekly, monthly, quarterly and annually. It also reported to employee council bodies with the same frequency. Its weekly reports contain data only, monthly reports add further comments regarding the reasons for certain precursors occurring, quarterly reports look at the root causes of incidents and precursors, and annual reports provide estimates of precursor rates for the upcoming quarters.
- A Finnish RU reported to the NSA monthly.
- An Italian RU had to submit quarterly reports to the NSA for all precursors.
- A Spanish RU submitted annual reports on precursors to the NSA but monthly reports internally.
- A Portuguese RU also submitted annual reports to the NSA except the reports were filed via the IM. The RU maintains close relations with the IM since the entities were separated and holds bi-annual meetings with the IM to discuss safety issues. The RU also has internal monthly reports that specify the frequency of precursors and compare rates to the preceding data for the year.

The reasons for NSAs requesting precursor data (beyond those specified in the CSI framework) were not always clear to RUs and IMs. According to one Italian RU, NSAs ask for more precursor data than is apparently necessary. The RU explained that there was little evidence of the NSA applying the data it was provided with, either for analysis or for making decisions that affected the RU, which led to this feeling that the NSA was making 'unnecessary' requests for data. Poor clarity as to why precursors are collected by NSAs was believed to have the potential to undermine the value of the process, and of reporting precursors to NSAs.

Key points:

- RUs/IMs reported precursors to NSAs with varying regularity (weekly to yearly).
- NSAs do not always appear to be transparent with the industry about their reasons for requesting precursors and how they will be used.

3.2.5 Summary of precursors monitored by RUs and IMs

Precursors that are not required by the CSI framework were typically developed by respondents using one or more of the following processes:

- Expert judgement
- Analysis of safety-related data collected at internal level
- Analysis of accident causation

This section outlines the range of precursors that are monitored by RUs and IMs in the sample.

Where precursors from different bodies were broadly the same, these were grouped and associated with the appropriate accident type for the purpose of the analysis that follows. This process required a certain amount of expert judgement given the variation in the terms used by different RUs and IMs, so the figures provided should be considered indicative only; however, the key details behind these figures are discussed in the sections that follow.

Table 14 shows the number of unique precursors that were monitored by RUs and IMs in the sample and disclosed to the study team. A wider range of precursors was monitored for derailment than any of the other selected accident types. A much narrower range of precursors was monitored for fires in rolling stock and collisions with obstacles. Overall, 66 unique precursors were reported by RUs and IMs in the sample.

Table 14: Number of unique precursors monitored by RUs/IMs in the sample for each of the six selected accident types

Accident type	No. of unique precursors monitored by RUs/IMs
Derailment	19
Collision with a train	16
Level crossing accident	12
Accidents to persons caused by rolling stock in motion	12
Collision with an obstacle	8
Fires in rolling stock	7

Table 14 shows the number of precursors that are monitored by RUs and IMs for each accident type. Rolling stock faults are clearly the most common type of precursor to be monitored, followed by human errors. Both of these types of precursor are monitored for all six accident types.

Table 15: Number of precursors monitored for each accident type by category

Accident type	Number of precursors by category				
	Rolling stock faults	Infrastructure faults	Human error	Environmental factors	Other
Derailment	7	2	7	2	1
Collision with trains	3	1	4	1	7
Level crossing accidents	1	1	2	0	8
Accidents to persons caused by rolling stock (excluding suicides)	2	1	2	0	7
Collision with obstacles	2	1	2	0	3
Fires in rolling stock	5	0	1	1	0

The following sub-sections provide a summary of the precursors monitored for each accident type, with a focus on the most commonly reported precursors.

Precursors for derailment

As shown in Table 15, rolling stock faults and human errors were the most common types of precursor monitored for that accident type. Of the seven types of rolling stock faults reported, multiple RUs/IMs reported the following:

- Braking system failures
- Hot axle boxes
- Wheel failures

The other rolling stock faults included other types of wheel and axle degradation, and general faults.

Of the seven types of human errors reported, multiple RUs and IMs reported the following:

- Loading errors
- General errors
- Errors by track maintenance staff
- Overspeeding errors (driver)

Infrastructure precursors for derailment were related to signal failures and faults of switches/crossings/points.

Environmental precursors for derailment included the effects of weather (e.g. floods, snow) and the effects of the landscape (e.g. rock fall, landslides).

Precursors for collisions of trains

Human error precursors were the most common type of precursor to be monitored for collisions between trains. Such errors included:

- Inattention
- Miscommunication and misunderstanding
- Driver error

The rolling stock faults that were monitored included general problems, braking failures and runaway trains. Infrastructure faults focussed on signalling failures. The range of other precursors monitored for this accident type included faults with systems that automate traffic management and train protection, and missing or inadequate signage on the railway.

Precursors for collisions with obstacles

The human error precursors that were monitored for collisions with obstacles focused on errors when loading rolling stock (leading to objects falling out of gauge) and general inattention and misunderstanding. The rolling stock faults that were monitored for this accident type covered braking failures and parts falling from the frame/underside of a train.

Precursors for level crossing accidents

The range of precursors monitored for level crossing accidents was more diverse than for the other accident types. With the exception of human errors related to inattention, misunderstanding and overspeeding, the other factors were wide-ranging and often related to interaction with level crossing users. On the infrastructure side, faults with level crossing equipment were monitored.

Some precursors within the ‘other’ category include user violations on level crossing, road vehicle incidents, and road vehicle driver actions.

Precursors for fires in rolling stock

There was a clear focus on monitoring rolling stock faults as precursors for fires in rolling stock, with hot axle boxes being the most commonly recorded precursor followed by other electrical and mechanical failures. The human errors that were monitored related to inattention and carelessness, and the environmental factors related to sources of external ignition.

Precursors for accidents to persons caused by rolling stock in motion

Human error precursors were the most common type of precursor to be monitored for accidents to persons caused by rolling stock in motion. Rolling stock faults were also monitored, particularly for door-related failures.

Other precursors monitored include accidental falls onto tracks, and injury to persons in and around the tracks.

Although it is difficult to draw conclusions from this sample of precursors from a small but diverse population of RUs and IMs, there were some identifiable trends:

- Human factors precursors comprised 10 sub-categories, of which the most commonly monitored were inattention and miscommunication.
- Rolling stock faults had two clear precursors that were most commonly monitored – hot axle boxes and braking system failures.
- Infrastructure faults were focused on monitoring precursors associated with signalling system failures.

Key points:

- More precursors are monitored for derailment than any of the other selected accident types. This is indicative of a sharper focus by train operators on the accident type that is likely to have the most severe consequences.
- Precursors related to rolling stock faults and human errors were the most commonly monitored types of precursor.

3.2.5.1 Levels of precursor monitoring

The purpose of monitoring precursors by those RUs/IMs surveyed is to detect incidents that have the potential to cause an accident. Presenting precursors within the structure of a fault tree highlights how precursors occur at different levels in the accident causation chain. These different levels of precursors were discussed by some respondents.

At least two Italian RUs defined precursors over multiple levels. One RU described its two-tier precursor monitoring: each accident type had precursors at the level of a 'dangerous event', each of which would have one or more 'primary causes' at a lower level. Dangerous events included the precursors specified in the CSI framework. The terminology used to define the two levels of precursors reveals much about the approach adopted by this operator: its SMS is geared towards preventing the dangerous events from occurring by identifying and actively monitoring the root causes of these events (which is what this RU considered as 'precursors').

As one Danish RU commented, there is considerable value in monitoring precursors lower down the accident chain because the consequences of some of the higher level hazardous events that are precursors to accidents can be rather severe (the example of smoke development on rolling stock was given, which is a precursor to a fire but still causes substantial disruption and potential damage). The cost-benefit case for precursor monitoring can often favour thorough monitoring of lower-level precursors, a point of view shared by a Swiss operator. This is because action on lower level precursors can often have broader safety benefits across several accident types (rather than targeting specific causes higher up the causal chain), especially as targeting precursors at lower levels may help to avert service disruptions and damage associated with the incidence of higher level precursors. It is noteworthy that 'cost-benefit' for precursor monitoring was proposed as a future direction for monitoring practices, as opposed to necessarily reflecting current practice. However, no information on this was requested as this was not the aim of the interviews, and the financial data in question is likely to be sensitive.

The inclusion of precursors at lower levels can lead to a vast range of precursors being monitored. In the case of one Austrian IM, approximately 1,500 precursors are monitored across the numerous levels below each accident type.

This multi-level approach to precursor monitoring contributes to fundamental differences in the definition of a precursor for some operators. Some operators (e.g. an IM in Austria) reject the definition that appears in the CSI framework (and is attached to the six European-level precursors) as these are seen as direct accident causes that occur too high up the accident chain to provide any scope for mitigation. For operators that take this approach, precursors are defined as potential causes that occur at lower levels in the accident causation chain. Conversely, other operators (e.g. an RU in Portugal) refer only to those direct causes of accidents defined in the CSI framework as precursors. This led to confusion when requesting information about precursors as this RU did not define the other incidents it monitored as precursors.

Overall, the advocates for lower-level precursor monitoring (which were primarily RUs in the sample), argued that this approach was preferable because mitigating actions taken to target lower-level precursors had:

- Greater benefits to safety overall.
- Broader effects that extended beyond a single accident type (e.g. staff training to address an issue related to one accident type may have benefits when staff undertake similar activities that may be a precursor for a different accident type).
- Better cost-benefit (it was argued that cheaper, 'softer' interventions were required lower down the causal chain, whereas more costly 'hard' engineering solutions were needed to mitigate incidents further up the causal chain).

Key points:

- The term 'precursor' is interpreted differently by RUs/IMs.
- Precursors can be monitored at different levels in the accident causation chain.
- Some RUs advocate monitoring lower-level precursors as they provide more scope for mitigation and thus fit with an effective SMS.

3.2.6 Rationale for developing precursors

In general, RUs and IMs reported that the monitoring of CSIs had been introduced by their organisation to satisfy European requirements for reporting, to carry out analyses of safety performance, and to use the findings to increase the level of safety. It is for the purpose of risk management that precursor monitoring has been extended beyond the six precursors specified in the CSI framework. One Austrian IM encapsulated the reasons for implementing wider precursor monitoring by explaining that while the six precursors in the CSI framework may be useful for monitoring at EU level, at an organisational level it was simply too few precursors to ensure safety was appropriately managed. Ultimately, this IM monitored precursors to identify measures that would enable the organisation to prevent accidents.

Additionally, some respondents stated that precursor monitoring was an essential component of a compliant SMS (e.g. an IM in Italy). From a wider perspective, the same Italian IM also explained that precursors were monitored to provide data to improve the railway in terms of quality and operational performance, as well as safety.

For some operators, their precursor monitoring preceded the European legislation that mandated monitoring specific precursors. For example, one RU in Portugal had collected precursors for many years prior to European harmonisation, although much of the data collected were paper-based and were never digitised to enable longer-term access and analysis. The preservation of historical data was also affected when the organisation was divided from an integrated RU and IM into separate entities.

For other operators, precursor monitoring had also preceded the European framework but had been adopted as a reaction to a sudden event. For example, the impetus for introducing precursor monitoring for one Italian RU was a high-speed train accident involving its rolling stock. When reviewing the value of safety monitoring prior to the accident, the RU acknowledged that simply monitoring the number of accidents that had taken place had provided no safety lessons. What was needed was knowledge of the precursors to accidents (specifically dangerous/hazardous events and their root causes). This RU thus created a database to begin monitoring precursors for this purpose.

One of the larger operators in the survey (a German company representing multiple RUs and IMs) monitored precursors in order to:

- Influence and direct its central SMS programme for the organisation;
- Pursue solutions to national safety problems (e.g. a current programme to work with German automotive manufacturers to incorporate level crossing locations in their satellite navigation systems); and,
- Engage with specific RUs and IMs within the enterprise to discuss what solutions are available centrally to deal with specific problems highlighted by precursor data.

Some precursors are used to trigger mitigating actions and must therefore be monitored regularly. One Dutch RU described how it used various precursors to trigger actions, such as:

- Concentrations of near misses at level crossing were used to notify police of violation hotspots. This precursor also triggered the RU's own education liaison officers to visit schools in the vicinity.
- High rates of door trapping prompted the RU to evaluate the training and competence of specific conductors, with a view to providing refresher training or issuing a training update.

An IM in Hungary also supported the use of precursors to highlight training needs among staff and also to structure the content of training for staff by providing a framework and practical examples from which staff can learn lessons.

Key points:

- Precursor monitoring has developed beyond the CSI precursors to enable operators to manage and improve their safety performance.
- Items monitored for quality and operational performance can also be precursors with respect to safety.
- RUs/IMs have historical experience of collecting precursors prior to the CSI framework, sometimes as a response to major accidents.
- Precursors help to target mitigating actions by identifying where and how resources should be deployed.

3.2.7 Approaches to precursor monitoring

Several different approaches to monitoring precursors were identified. This sub-section presents examples provided by the RUs and IMs in the sample but does not aim to compare and contrast the different ways of monitoring precursors with a view to identifying a recommended approach.

Devolved monitoring of precursors

One approach that was detailed by an Italian RU with national coverage appeared to be established around a type of 'devolved monitoring' (i.e. precursor data collated and investigated locally before being fed back to a central point). The RU utilises its local operational sites across the country to facilitate precursor monitoring. A safety manager is based in each of the 40–50 towns from which the RU runs its operations. Each safety manager is responsible for collecting weekly all the 'dangerous events' (the higher of the two levels of precursors collected by this RU) that involve trains in circulation and during shunting. As part of this process, safety managers correspond with colleagues who have the expertise to provide information about the primary causes of these dangerous events (the lower of the two levels of precursors collected by this RU). The outcome is a record in the RU's precursor database of dangerous events (higher level precursors) and their primary causes (lower level precursors).

In addition to recording events and investigating their causes, the process also considers mitigating measures, which can be recorded on the same intranet-level database for reference across the RU. Mitigating actions are always linked to primary causes rather than dangerous events (lower rather than higher level precursors) as this is where the RU believes it can exert the greatest influence. Thus, when a precursor is reported, staff can look back over the database to see what actions were taken before to help guide the actions they may take now. This systemised way of sharing experience was reported to be more reliable than the sharing of experiences directly between staff. Figure 9 provides a graphical summary of the process.

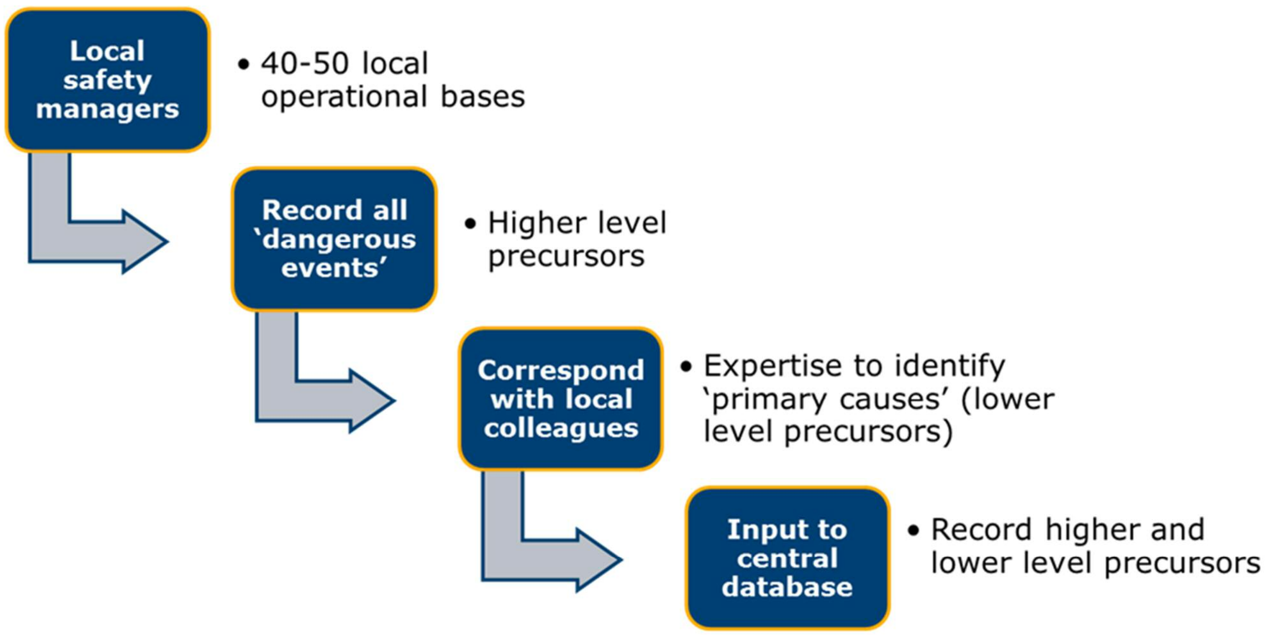

Figure 9: Diagram of distributed data collection process described by one RU

Historical re-classification and investigation of precursors

Another approach to monitoring precursors was adopted by a Danish RU. The process began with an historical review and reclassification of one particular precursor (SPADs) into seven sub-categories (see section 3.2.13). This was followed by an investigative process whereby all drivers involved in such incidents during the last two years were interviewed to identify the root causes. This process of investigation alongside monitoring has now been implemented for all new SPADs as well: the signal command centre informs an operating investigator at the RU if a SPAD occurs and the investigator immediately calls the train driver to discuss what happened. Specially-trained investigators are available to take over the case if it has interesting factors (e.g. mobile phone use). Root causes for incidents are captured but are not yet recorded as specific precursors (the RU intends to develop and link its precursor database with these lower level causes once concerns can be overcome regarding the consistency of defining a range of primary causes, such as different types of human factor).

This process of close monitoring and interviewing has halved the number of SPADs for this RU. Specifically, the reduction has come from three depots with drivers that serve on lines without ATP, where there was a high danger potential. Prior policy was not to discipline drivers for SPADs; now each SPAD from the last five years is linked to the driver. Those with three SPADs receive a warning and those with four SPADs lose their job (two drivers have lost their positions since the policy was implemented). This approach demonstrates that rigorous precursor monitoring and investigation can:

- Identify root causes of the most dangerous events and enable policies to be implemented to actively target that risk.
- Generate passive safety benefits by developing the safety culture in the company and sending a clear message to staff regarding its importance.

Grading the severity of precursors

When precursors are reported they can be graded to reflect their severity. This adds an element of granularity to precursors to reflect that two precursors of the same type can be substantially different. For example, axle corrosion can vary in intensity from mild to severe, and it may be localised or widespread; knowing the severity of the precursor when it is reported is essential for calculating the risk and for planning mitigating action. In another example, wheel flats were graded by the entity in charge of maintenance (ECM) for one Danish RU according to the size and location of the flat spot. The RU considered this data useful for assessing safety performance. However, the data were not currently available to the RU; instead severity was rated by the ECM for passenger comfort and maintenance scheduling and, as the wheel flats were detected in advance of becoming a safety hazard, the data remained internal to the ECM. Consequently, these data were known to the RU but not reported to it, even though they would be of value as lower level precursors of more serious rolling stock failures. Inherent in this example is the problem of relevant precursor data being collected within rail operations for purposes other than safety management that could readily be applied to safety management if there were consolidation across data reporting systems (see section 3.2.12 for a wider discussion). This particular RU saw the value of exploring what safety-related data may already be gathered elsewhere in its organisation and was planning for wider integration of data sources in the future.

Key points:

- Two main approaches to precursor data collection in RUs/IMs were reported: centralised data collection by a core team of investigators, and distributed data collection by local investigative units.
- Irrespective of how precursors are collected, it is important to investigate and record the root causes of each event.
- Historical investigation of root causes can help to fast-track the development of a comprehensive precursor database.
- Mitigating actions to address hazards can be linked with the relevant precursors in a central database to provide all staff with access to agreed safety management procedures.
- Investigative actions and policies based around precursor monitoring can passively increase staff awareness of safety management and can develop an improved safety culture.
- Data collected by separate departments or contractors within a railway organisation may have safety-related value.

3.2.8 Precursor continuous improvement

It was evident that respondents wanted their systems for monitoring precursors to evolve to reflect new knowledge. The process of continuous improvement was seen as vital to maintain an efficient programme of precursor monitoring; resources can be wasted focusing on precursors that are poorly defined or contribute no value to accident prediction or wider safety management.

One Italian RU was proactive about the evolution of its precursor database, encouraging a quarterly review by the central safety department to add, remove or revise the set of precursors that it monitors. The review considers any trends in the data that may require a response.

Monthly data were collated by an Austrian IM as part of precursor surveillance: these data then contribute to a quarterly review (survey and audit) to check how well the safety management system is working and if it is meeting its targets.

A similar approach was adopted by other respondents whereby precursor data were reviewed internally by committee on a regular basis (e.g. monthly) except the decision on which precursors to add, remove or revise was only made annually. A Spanish RU reported carrying out an annual update that was supported by a monitoring programme that collected data daily.

A German operator (representing RUs and IMs) reported that it also reviewed and updated its set of precursors, as evidenced by the growth and adaptation of its own database over the last 20–30 years. Reviews could be prompted by accidents shedding new light on root causes, and technology providing more detailed information about precursor events (e.g. black box technology in locomotives helping to identify all of the events leading up to an accident). Moreover, the central safety team holds regular discussions with those responsible for precursor monitoring at the different RUs and IMs across the organisation to identify whether any precursors at operational level should be monitored centrally by the organisation.

Key points:

- Precursor monitoring must remain efficient, perhaps through the consolidation of precursor data into a centralized database. This will free up staff time resources for analysis and finding solutions to improve safety.
- Precursor data are reviewed—and the framework for data collection updated—at least annually.
- More proactive approaches exist, where precursors are reviewed regularly by committee.

3.2.9 Precursor analysis

Analysis of precursors was commonly undertaken by the central team that was responsible for collecting precursor data for each RU/IM. However, not all operators sought to centralise precursor data analysis. One of the larger operators in the survey (a German company representing multiple RUs and IMs) opted to make the individual RUs and IMs within the parent company responsible for analysis of their own precursor data. However, it could be desirable to exploit opportunities to share resources and processes for analysis across parts of an organisation, especially between operational elements that are very similar.

A Finnish RU stated that, in principle, precursor data can be analysed to predict accident probability but the scarcity of precursors and accidents in its operations made this difficult to achieve. This point was echoed by an RU in Portugal that confirmed it had not seen an accident that was associated with any of the six CSI precursors for up to 10 years so predicting accident frequency on the basis of the precursors required at European level was inexact.

Analysis of trends in precursor data can also lead to the development of internal safety targets, as set by at least one RU (in Spain). Although this Spanish RU did analyse the association between precursor frequency and accidents, the targets it set for precursor reduction were not necessarily based on the relative contribution of each precursor to an accident but on the need to maintain safety overall and accomplish targets. The RU was developing a software program that would assist with precursor analysis by modelling precursor data so that it could be applied to different operational and accident scenarios.

Normalising data

The numbers of precursors alone are not sufficient when making comparisons between different railway infrastructures because they do not allow for differences between the size of the network, the number of train movements, number of passengers, or any systematic difference in the nature of the network. To be useful to ERA, the raw statistics must be divided by a scaling parameter, or normaliser, that is representative of the scale of the network or its use. The normaliser that is used for any particular precursor is of critical importance since performance could be distorted if the normaliser is not entirely appropriate for the precursor concerned (UIC Safety Platform, 2005).

Respondents were asked about the use of normalisers when interpreting precursor data. Normalisers were typically used when analysing data over a number of years or when drawing comparisons with other operators and networks. RUs and IMs were somewhat divided over the use of normalisers internally. Several did not normalise data when analysing precursors over shorter periods of time, although there were exceptions (e.g. RUs in Denmark and Portugal).

Prioritising precursors

Analysis of precursors is sometimes quite rudimentary – for example, one RU in Portugal described how it prioritised precursors for mitigating action based on their frequencies alone, and allocated resources to deal with all precursors in that order. This approach to prioritisation did not consider consequence severity, allowing priority to be given to mitigating frequent events that may not have severe consequences. Further analysis of precursors (e.g. in fault trees) was not yet attempted by this RU due to a lack of resources.

One Italian RU analyses its precursors to identify those that are associated with the highest risk incidents (i.e. it considers the frequency of occurrence and the average consequence severity). Its concern is that precursor frequency alone does not provide an indication of those that are the greatest safety risk. For example, it reported that shunting incidents can be very frequent (and sometimes expensive in terms of damage) but rarely involve injury to persons. Similarly, some dangerous events involving freight can occur often (such as open cargo doors) but the resultant accidents have—usually—few consequences. Likewise, tail light failures on rolling stock were reported frequently but in only one instance did this RU recall an injury occurring as a result. From a safety management perspective, this RU did not consider it efficient to prioritise precursors using frequency data only. This would overlook the low-frequency, high hazard events that can cause substantial harm.

Associated benefits of analysis

The process of analysing precursors was seen to foster the development of an active safety culture within each operation, and encourage a deeper understanding of what matters most to the safety management of that organisation. For example, the German operator explained that some of the precursors it monitored were, when taken at face value, of little interest; SPADs, for example, were not seen as significant precursors to collisions due to the safety net provided by ATP. However, when the root causes were investigated it became clear that the occurrence of SPADs provided insight into other safety-related issues, such as:

- Poor staff/driver concentration, and human factors issues in general
- Technical problems (e.g. degradation or malfunction of the railway due to weather/age)

Key points:

- Precursors may be prioritised for monitoring and mitigating action based on:
    - Frequency alone (considered less efficient)

  - o A balance of frequency and consequence severity (considered more efficient)
- Normalisers are applied to precursor data when comparing operators/member states or analysing over time.
- Analysing root causes of specific precursors can highlight broader hazards related to staff competence, training and technical problems.

3.2.10 Precursor quality and reliability

The accuracy, quality and reliability of precursors can vary, particularly for precursors that rely on staff reporting rather than detection by an automated system.

Operators are advised to be efficient when reporting and recording precursors, and to be aware that external events can influence the reporting process. For example, one Italian RU reported that, following the freight accident at Viareggio, precursor data monitoring indicated a rise in the precursors related to that accident type. Initially, there was concern that the safety situation was worsening but in fact it was simply a surge in reporting of the primary causes. This was attributed to greater staff awareness of precursor monitoring (i.e. a change in the safety culture). It also highlighted that although the RU was confident that higher level precursors were monitored robustly, the monitoring of lower level precursors was variable.

Operators can implement processes that enable them to monitor the accuracy of the reporting process. For example, one Italian RU has regular communication between its central safety department and each of the safety managers responsible for local precursor data collection to ensure that the process is consistent. Similar processes were described by those responsible for precursor data collection in other RUs and IMs.

The reliability and accuracy of some precursors was reported by an Austrian IM to be variable due to some precursors being easier to detect and monitor than others. This has meant that some of the 1,500 precursors within this IM's monitoring system are not used in the modelling or statistics that are produced.

Underreporting

The specific problem of underreporting of precursors was commonly attributed to:

- Lack of knowledge and experience amongst frontline staff of what constitutes a precursor and when it should be reported.
- Poor safety culture whereby staff are reluctant to report precursors for fear of blame being directed at themselves or colleagues.

Issues of underreporting were considered lower for incidents where there was greater potential for the staff member to suffer harm. A Dutch RU gave the example of near misses with users at level crossings: drivers were typically good at reporting these incidents because they were known to have a cumulatively damaging effect on mental well-being and health.

Key points:

- If staff are responsible for detection and reporting, precursor reliability can vary due to:
  - o External/internal events that influence staff safety culture
  - o Inconsistency in reporting procedures
  - o Poor knowledge and experience of precursors
- Underreporting of precursors can be exacerbated by a 'blame culture'.

3.2.11 Difficulties associated with monitoring precursors

This sub-section outlines some of the common difficulties with precursor monitoring reported by RUs and IMs.

Company support for precursor monitoring

Resource limitations were cited (by an RU in Italy) as one difficulty associated with precursor monitoring. There has been an increase in competition in recent years (particularly between RUs) that has led to greater focus on maximising train and track capacity and profitability, in the opinion of this RU. It was suggested that the resources and priority given to safety management may have suffered as a consequence. A Dutch RU had similar experience of precursor monitoring being branded by management as a 'box-ticking' exercise and an administrative burden because of the regulation – attitudes that also bring with them complacency. It argued that management and staff need to be persuaded of the value of precursor monitoring and encouraged to engage with the process. To address these difficulties within its own organisation, the RU had carried out an internal evaluation of how it used precursors. It subsequently introduced changes to improve staff engagement with the process: the monthly report format was adjusted so it had more information to assist staff with improving day-to-day operations, the administrative burden of reporting was partly addressed by updating computer software and hardware for reporting (with standardised training and instructions to accompany this), and introducing a safety culture improvement programme, which included reassurances to staff that they would be protected from prosecutions that could arise from hazard reporting. 'Blame culture' must be avoided: the perception that reporting may result in someone being blamed could discourage reporting, even if it would not be the person making a report that would be blamed). Similar organisational change to support precursor monitoring and analysis was also desired by an RU in Portugal. 'Just culture' builds on the shortcomings of 'blame culture' and appears to be predominant in the medical industry. Discussion of how this could benefit the rail industry is beyond the scope of this study.

Manual precursor monitoring

One Bulgarian RU commented on the difficulty of monitoring precursors for which there are no automated detection systems, and for which there is a need to take the train out of service to undertake the necessary checks. It gave the example of monitoring for parts that fall from the underside of rolling stock. The RU stated it cannot easily check when this happens as it relies on human observations to detect such failures. Some elements of the undercarriage are monitored routinely at depots but this monitoring process does not capture all aspects. Inspections may not be as frequent or as thorough as required because such inspections require access to the underside and must be done when the train is out of service at a depot. Therefore, the RU acknowledged that some objects that fall from the underside 'simply happen' and cannot be forecast easily. If the monitoring regime was automated, or the precursors were part of normal management data that were gathered for operational reasons, this precursor could be monitored with the same rigour as other precursors.

Restricted range of precursors

Common among RUs and IMs were concerns about how to broaden precursor monitoring to include maintenance and operational performance indicators, rather than safety indicators exclusively. Precursors that are associated with the condition of trains are often not classified as safety indicators, according to two RUs (in DK and AT). Their experience of working with ECMs was that they would be focused on fixing trains and keeping them in service, with fault-reporting not oriented from a safety perspective. However, many of the data they collect could have implications for safety if situations were allowed to develop further.

An RU from the Netherlands agreed that it was difficult to establish the level of severity at which a precursor becomes a genuine safety risk, especially when considering rolling stock faults (e.g. levels of axle corrosion). Often a common-sense approach must prevail, that balances safety with the operational demand to keep vehicles in service. However, developing systems for monitoring precursor severity require all data to be reported, rather than just those examples where the ECM has used its own judgement to decide that there was a safety risk worthy of reporting.

Misinterpreting changes in the data

Several respondents were keen for it to be noted that when precursor frequencies increase, this may reflect improved monitoring regimes rather than a growing safety risk. It was a common concern that the current presentation of precursor data in Europe did not reflect this in some way. It may be a disincentive to organisations seeking to improve their monitoring procedures if higher frequencies are considered out of the context of the overall safety level.

Changing the 'safety culture'

A challenge for several respondents (e.g. a Dutch RU) was to overcome the reluctance among staff to report safety hazards, particularly those that involve other staff directly (e.g. failure to dispatch trains safely). A change in safety culture to remove any 'blame culture' and make reporting safety hazards more acceptable was considered desirable by several operators.

Data sharing

Data on some precursors may be monitored by one organisation but be valuable to multiple organisations. For example, two Italian RUs and one Spanish RU found it difficult to obtain data on relevant precursors that were managed by the IM, despite requiring them for safety management purposes. The Spanish RU explained how this led to an annual set of incident data related to infrastructure problems that was different to that calculated by the IM. In essence, this RU was highlighting the difficulties associated with assigning the reporting of incidents that occur on the railway to either an RU *or* an IM; this approach seeks to overlook the fact that the two functions are often interrelated, and incidents that affect rolling stock may have causes that originate from the rail infrastructure, and vice versa. This particular RU stated that it was important to have data on precursors and incidents that occur on the rail infrastructure (e.g. track faults) to fully understand its own precursors and incident rates as an RU. In contrast, an RU from Portugal described how it had regular communication with the main IM to share precursor data and report jointly to the NSA.

Data management

One Spanish RU reported difficulties with monitoring precursors due to the absence of a central database (although this has since been established). One German organisation (representing RUs and IMs) commented that too many data were occasionally a problem when monitoring precursors.

Further difficulties with precursor monitoring were created by European definitions for precursors that required greater clarity. One such example is discussed in Section 3.2.13.

Key points:

- Increased market competition and limited resources can reduce support for precursor monitoring within an organisation.
- Precursor monitoring can be viewed as an administrative burden and, if operators fail to engage with the process, complacency may set in.
- Operators are often restricted to monitoring safety-related precursors due to the difficulties of capturing data on other indicators (e.g. related to maintenance) that are captured by ECMs. This presents missed opportunities to capture certain precursors at different levels of severity.
- Improved precursor detection can lead to increased rates of reporting, which may be interpreted externally as a decrease in safety performance.
- A 'blame culture' can deter precursor reporting by staff.
- Safety management can be hampered by RUs and IMs that operate on the same network not sharing precursor data.
- Difficulties with data management can emerge if there is not a central precursor database within the RU or IM.

3.2.12 How to improve precursor monitoring

This sub-section outlines suggestions for how to improve precursor monitoring based on the operational experiences of RUs and IMs.

Automated and consolidated data collection

Automation and consolidation of data collection was recommended by one Italian RU. It recognised that precursor data were often collected at lower levels by departments that carried out functions for the RU (e.g. ECMs and wagon keepers). Some of these data were collected by the RU so they could be included in the database of precursors; however, the process of collecting these data requires substantial staff and time resources. There is an opportunity to consolidate the data collection systems used by departments serving an RU so that precursor data are sent automatically to its central precursor database. This would also enable more precursors to be monitored at a lower level (for example, ECMs may detect many lower level precursors during maintenance programmes that would be valuable for understanding the causes of hazardous technical failures in rolling stock). An associated benefit of consolidating databases is that resources currently invested in data collection can be re-allocated to precursor analysis, which should benefit safety.

This suggestion was echoed by a Danish RU. It gave the example of rolling stock fires, for which the ECM would investigate the root cause but often this would not be fed back to the RU precursor database, which is where data consolidation between ECMs and RUs would be beneficial. Although the exchange of precursor information upwards from the ECM to the RU was limited, this was not the case in the opposite direction. For each precursor related to a rolling stock fault that was detected during operation by the RU, the RU would maintain a record of the type of rolling stock affected and then feed this information back to the ECM so it could check if there was a need to update maintenance requirements for that particular type of stock.

An Austrian RU expressed similar concerns; in its experience, the ECM and registered keeper of its rolling stock were in receipt of data on monitored axle temperatures (to indicate hot axle boxes) but did not share these data with the RU. This was a concern for the RU given that these data constituted a lower level precursor for one of the higher level precursors (broken axles) that was monitored by the RU. In addition, this Austrian RU hired its drivers from third parties, which created another organisational barrier in the chain of precursor reporting that would need to be overcome through better liaison.

For improved precursor monitoring, one RU (from Bulgaria) suggested that it is important to lower the dependence on human factors, such as relying on drivers to report faults with rolling stock. Improved automation of systems for precursor monitoring was advocated.

Internal and/or national rules for RUs and IMs governing the reporting of precursors can encourage staff to report those precursors for which there is no automated system of detection. An RU in Portugal stated such rules governed its staff and appeared to be effective, with drivers, signallers and other staff all inputting to the precursor database. The exception to this was for precursors where staff may be reporting incidents that could be attributed to them: this RU did not operate a 'no blame' system and held staff fully responsible for errors when appropriate.

National precursor data collection

To overcome the difficulties associated with disparate data collection, one Italian RU recommended creating a national system for recording precursor data that shared all safety-related data between rail operators. At a national level, a Spanish RU also recommended a common accident and precursor database. Furthermore, this RU suggested that the NSA should seek to unify the different definitions used by organisations for incidents and precursors to enable a common, single database. Related to this, one RU from Portugal described how the NSA and operators would meet to discuss any accident that has occurred, from which mitigation measures could be implemented to prevent further occurrences; however, these meetings were often held a long time after the accident and this RU advocated sharing the information far faster. Collectively, these respondents believed that more improvements to safety would come from RUs and IMs working together nationally on precursor monitoring, rather than at a European level.

Investigative staff

Having an investigator on hand to explore the root causes of incidents that occur during train circulation is apparently fundamental to obtaining valid knowledge and insight, and developing robust precursor monitoring systems according to one Danish RU.

Accident investigation and dissemination of knowledge

NIBs across Europe could better disseminate information about accidents and their causes, particularly from a human factors perspective, in the opinion of several RUs (e.g. DK, AT). For some RUs (e.g. FI), accident investigations also need to be more thorough in their consideration of root causes, as it was confident that this is where future safety benefits can be realised. An RU from Austria wanted this to develop a step further so that the exchange of experiences following notable incidents or accidents were shared throughout the industry, at least at a level that was supported and reinforced nationally.

RUs and IMs should be open to learning from successful examples of precursor monitoring and analysis from recognised organisations was a suggestion from one Danish RU. It saw little value in attempts to develop such systems independently of the knowledge and experience that already existed. The RU cited the British system of precursor monitoring as an example from which to learn.

A core theme that has emerged from these suggestions to improve precursor monitoring is that safety management is a holistic process that intrinsically requires the support of holistic precursor monitoring. The collation of disparate data sources from across an RU or IM will help to achieve this goal.

Key points:

- Data consolidation across the different operational elements of an RU/IM is desirable to build a comprehensive precursor database.
- Automated data consolidation (e.g. from ECMs) would improve data collection rates but not carry a cost in terms of staff resources.
- Greater automated detection of precursors is desirable to eliminate selective reporting by staff and to maximise resources for precursor analysis and safety management.
- Precursor monitoring at a national level could generate a collective safety benefit for RUs and IMs within each member state, based on shared knowledge, unified precursors and faster information exchange.
- Root causes of accidents identified through investigation (e.g. by NIBs) can benefit RUs and IMs if they are disseminated more widely across Europe, or at least nationally.

3.2.13 Europe-wide monitoring of precursors

This sub-section outlines the opinions of RUs and IMs towards the existing regime of precursor monitoring in Europe, as specified in the CSI framework.

Defining, comparing and interpreting current European precursors

One Italian RU was not convinced that collecting precursors at EU level would have any value until Europe was able to define requirements for homogeneous precursor data collection. It stated that the current situation allowed for too many variations in how the precursors were defined and from which railway systems they were collected. To assist with comparison of data for the existing precursors specified in the CSI framework, it was recommended (by one Spanish RU and one Austrian IM) that each precursor should receive a more specific definition that would enable more accurate comparisons to be made across European member states – as one Austrian IM commented, there is scope to develop a common understanding of each precursor across European states. This would develop the existing data into a source of useful safety information, a function that this IM believes it currently does not fulfil.

Moreover, the general poor quality of data—and poor comparability across member states, RUs and IMs— may have a damaging effect on the perceived value of precursor data across Europe. This could discourage other organisations from further development of precursor monitoring.

Indeed, a German operator concurred that a key problem is the need to compare data at a European level in a way that reflects actual safety performance. It noted that some member states can appear to have a poor safety performance when CSI data and CST performance are considered, yet it is recognised that some of these member states actually have admirable safety standards that are acknowledged to be some of the best in Europe. If current CSI data are not genuinely reflective of actual safety performance then there is a need to establish better processes for interpreting and presenting precursor data.

One Dutch RU noted that current European precursors related to rolling stock (e.g. broken axles) were potentially more informative when comparing across member states because the majority of rolling stock would have axles of the same (UIC) specification. It recommended basing potential expansion of precursors on components that are subject to similar levels of standardisation across Europe. By extension, this RU believed that future precursor monitoring will be more comparable on a European basis once the TSIs become more widely adopted and legislated across Europe. This will create common infrastructure systems on which precursors can be based for comparison.

Precursors specified in the CSI framework

Respondents were invited to discuss their views and experience of monitoring the six precursors specified in the CSI framework.

One Italian RU stated that the range of precursors specified in the CSI framework was too narrow and the list should be expanded. It also recommended that CSI precursors are monitored at levels that can lead to improvements in safety, which it identified as the lower level 'primary causes' of accidents (i.e. are at a level where mitigating action can reduce the occurrence of hazardous events further up the accident chain). Specifically:

- Primary causes of Signals Passed at Danger (SPADs)[11] are not monitored – SPADs can occur for a variety of reasons (many of which depend on the type of railway system) so collection of data without this information provides no indication of safety levels.
- Track buckles have a similarly wide range of causes that can include technology, the environment and human factors, and root causes therefore should be recorded.

Some of these views were shared by other respondents, such as one German company that has a joint RU/IM role. It stated that SPAD frequency could not be compared between member states due to variations in train technology. This was particularly pertinent for lines with and without Automatic Train Protection (ATP) of some type. On lines with ATP, it argued that the accident potential for a SPAD was minimal but the automatic detection created an anomaly whereby the high rates of reported SPADs were indicative of a fully operational protective system rather than a substantial risk. (Nevertheless, it did specify that such SPADs were useful for further analysis of root causes—see section 3.2.9). The operator suggested that to provide benefits as a precursor, SPADs should be sub-categorised at European level to include information on:

- The type of rail system where the SPAD occurred (and if ATP was present)
- The traffic conditions under which the SPAD occurred (in circulation or during shunting)
- The specific circumstances of the SPAD (e.g. occurred during train dispatch)

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[11] The relevant text of the Directive in English, French and German reads:

- Total and relative (to train kilometres) number of signals passed at danger
- Nombre total et relatif (par kilomètre-train) de signaux passés en situation de danger
- Gesamtzahl und (auf die gefahrenen Zugkilometer bezogene) durchschnittliche Zahl der unter Gefährdung überfahrenen Haltesignale

The text in English means that a signal has been passed (without authority) whilst displaying a "Stop" ("Danger") aspect. This is very different from the other two language versions.

UIC recommends that a single definition should lead to all parties being required to record as a SPAD any occasion when "any part of a rail vehicle proceeds beyond the limit of its authorised movement".

Such categorisation would also provide further clarification regarding the definition of a SPAD. For example, this German operator recently had to adjust the way in which it reported SPADs to Europe to remove all instances where drivers were permitted to proceed against a signal at danger due to a technical problem in the signalling system: they were not SPADs in the intended sense of the term as they were authorised 'violations' although the ATP system still recorded these as SPADs. This, the operator argued, highlights one of many inconsistencies in reporting procedures (in this case, due to the type of technology used) that make comparisons across different networks less meaningful.

Similar recommendations were made by this German operator with regard to the CSI monitoring of broken rails and track buckles. Again, it felt more contextual information was required because it had reported increased rates for these precursors that were attributed to improved detection rather than higher frequency. It felt that the most relevant contextual information would be to report all precursors alongside the number of associated accidents. This could be supplemented by European guidance to indicate when the ratio of recorded precursors and associated accidents reached different levels of severity. The objective would be to prevent precursors from being considered in isolation as they are currently.

From the perspective of an RU, contextual information about broken wheels and axles was considered a minimum requirement for reporting. One Austrian RU stated that these precursors were not useful for an operator without further information on the root causes—information that could then be considered when updating maintenance and inspection procedures for rolling stock.

An RU in Portugal supported the general call for further contextual data to underpin the reporting of all CSI precursors.

The sub-categorisation of SPADs was supported by other operators. For example, one Danish RU actively monitored seven sub-categories of SPAD (Table 16). They are listed in order of their danger potential, from highest to lowest, the purpose of which is to enable the RU to identify the most dangerous types of SPADs with the objective of working towards their reduction. This re-classification of SPADs was implemented retrospectively too so that the RU could reach a current assessment of the safety implications based on data gathered during the preceding five years. By gaining a more detailed understanding of what types of SPADs were happening, the RU was able to identify and implement appropriate mitigations to prevent half of the SPADs occurring. The value of this was clear: the RU managed to halve the number of SPADs by moving from the NSA definition of a SPAD (which was linked to the CSI definition) to a more detailed set of definitions. The value of this has been recognised by the NSA, which has redefined its national definitions of SPADs after consulting with the industry and recognising the associated safety benefits.

Table 16: Sub-categories of SPAD monitored by an RU from Denmark

SPAD sub-category	Description
1. SPAD - train crosses danger point	A SPAD where the train crosses the danger point
2. SPAD - train stopped before danger point (not stopped by ATP)	A SPAD where the train stops before the danger point but not using ATP
3. SPAD - passed during braking phase due to extenuating circumstances	A SPAD where a train has attempted to brake but has passed the signal due to extenuating circumstance, e.g. poor braking power
4. SPAD during shunting (centralised traffic control)	A SPAD during shunting when there is centralised control of traffic
5. SPAD during shunting (hand signalling)	A SPAD during shunting when there is no centralised control of traffic and hand signalling is used
6. SPAD using block signalling traffic control	A SPAD that occurs when a train is using the block signalling style of traffic control, where the driver is responsible for operating control posts along the track to indicate when a section is in occupation
7. SPAD - train braked by ATP before danger point	A SPAD where a train has passed the signal and ATP has stopped it before the danger point.

The six precursors specified in the CSI framework were considered by one Finnish RU as too focused on significant accidents, which was not helpful to understanding and improving safety at individual RU level.

One IM from Italy believed that three of the four precursors in the CSI framework that related to infrastructure were very useful to the organisation, with the exception of wrong-side signalling failures, which were less useful because the definition provided was unclear.

Developing European precursors

One RU from Denmark had been motivated to act in response to its dissatisfaction with what it saw as 'poor quality' European data, especially for benchmarking purposes. This RU has sought to develop a working group with other operators from NL, SE and NO for benchmarking purposes. The working group is initially to focus on SPADS; through a series of visits and workshops the group will establish equivalent definitions to enable meaningful comparisons between their operations. The RU recognised that it was possibly counter-productive to focus activity in a smaller group rather than making use of the EU platform for cooperation—and that the process could undermine the value of wider European activities in this area. However, this RU promoted the value of cooperation at lower levels in Europe, between smaller groups with common interests. It also highlighted the associated benefits of such close collaboration, such as refining elements of its SMS, or its response to different CSMs, in conjunction with other RUs in the group.

Whether such developments should influence the wider European rail industry was open to debate. One Dutch RU cautioned against the development of 'burdensome' European requirements for further precursor monitoring. In the opinion of this RU, the value of certain precursors will vary between operators and some precursors that reveal little of the safety performance of one operator will be considered valuable for the safety performance of another. SPADs on lines with and without ATP were offered as an example: for operators running services without ATP, SPADs are singularly important to monitor. This RU did not want European requirements for monitoring precursors to become so burdensome that they would undermine and overshadow the resources required to monitor current precursors that are essential to safety. An Austrian IM concurred with these arguments for similar reasons, adding that the EU should not demand too much from individual countries and organisations.

Key points:

- The CSI precursors have definitions that are interpreted differently by RUs/IMs.
- Comparison of CSI precursors between different member states is imprecise due to the different interpretations of the definitions.
- CSI precursor reporting would benefit from greater context, such as the number of reported accidents associated with each causal factor.
- Precursors with greater detail are more useful to operators when planning mitigating actions.
- RUs and IMs would prefer a precursor reporting system that permitted the safety performance of each member state to be graded against agreed criteria, rather than inferred from raw data.
- Small groups of member states have collaborated to improve precursor monitoring among their own operators for benchmarking purposes.

3.2.14 Recommendations for precursors to be monitored at European level

The consultation with each RU/IM concluded by asking each to recommended up to three additional precursors for monitoring across Europe. Where appropriate, the three precursors were ranked in order of importance by respondents, from '1' (most important) to '3' (less important). Table 17 provides the full list of 20 precursors that were proposed, with the corresponding average rank (computed by taking the mean of the ranks provided by respondents), and the associated member state for each of the RUs/IMs that proposed the precursor.

Of the nine precursors that were given top priority, two were expansions of existing CSI precursors for SPADs and broken axles (the recommended action was to monitor a range of sub-categories for each). There were similarities between the proposed precursors for European monitoring and the precursors that RUs/IMs reported they already monitored (as described in section 3.2.5). For example, hot axle boxes and signal failures were two of the specific precursors given a high priority, and these were also two precursors that were already widely monitored by RUs and IMs in the sample.

Of the five precursors that were ranked as second priority for European monitoring, one was an expansion of a CSI precursor for broken tracks – again, the recommended action was to add a range of sub-categories to be monitored. Precursors related to human factors issues were proposed by respondents from three member states as a second priority precursor, once more mirroring the responses in section 3.2.5. Another of the precursors ranked second in priority was a suggestion for an 'SMS performance' precursor. This idea was proposed by a respondent that believed there was scope for a precursor that was based on the ratio of unsafe measures recorded in an SMS to the number of successful mitigating actions that were implemented. The concept behind the proposal was to have a precursor that reflected the amount of effort given to safety management by RUs/IMs.

Of the six precursors that were ranked as third priority for European monitoring, two were developments of the CSI precursors for broken wheels and track buckles. As before, the recommended action was to introduce sub-categories for these precursors. Of the other precursors ranked third priority, two related to objects falling from trains (either from the load or from the train itself).

Overall, it is notable that of the 20 precursors recommended for European-wide monitoring, all six of the precursors in the CSI framework were represented, albeit with the specific recommendation that each should have sub-categories that enable a more accurate set of circumstances to be recorded.

Table 17: Precursors recommended by RUs/IMs for Europe-wide monitoring, by rank

Precursor	Rank	MS
Broken axles (sub-categories)	1	BG
Near misses	1	ES
Obstacles on the line	1	IT
Rolling stock failures	1	ES
Train running into an occupied track with standing vehicles	1	DE
Train traversing level crossing with debris on track	1	IT
SPADs (sub-categories)	1.2	DK; NL; ES; PT; BG
Hot axle box	1.5	AT; BG
Signal failures (sub-categories)	1.5	BG; DK
Ascent and descent from the moving train	2	IT
Broken tracks (sub-categories)	2	PT
Human factors	2	AT; DK; DE
Incorrect manoeuvre	2	IT
SMS performance	2	NL
Broken points/switches/turnouts	3	BG
Broken wheels (sub-categories)	3	BG
Non-compliance with written orders from traffic controllers/signallers	3	NL
Track buckles (sub-categories)	3	PT
Train losing parts of the load	3	DE
Train losing parts of the vehicle	3	DE; BG

3.3 Summary

The consultation suggests that rates of precursor monitoring by RUs/IMs are high (over 90% of the respondents in the sample), though the sample of RUs and IMs was selected to be as informative as possible. Collectively, those RUs and IMs that have reported monitoring precursors represent a wide range of operators in terms of size, traffic levels and geographical location in Europe. They also represent a wide range of European member states, from those with the largest rail networks to those with some of the smallest. It can therefore be assumed with some confidence that precursor monitoring is extensively practised across the European railway industry.

However, the extent of precursor monitoring did vary. It was clear from the sample of respondents that some organisations monitored very few precursors and others monitored an extensive list. There appear to be several explanations for this difference. Firstly, some organisations have simply not developed their system of precursor monitoring to the same extent as others have. (Unfortunately, given the small numbers involved, it was not possible to come to a robust conclusion on this factor based on the available data.) This may be partly due to the second reason, which is that some organisations have opted to monitor precursors at a much lower level in the accident causal chain, which typically increases the number of precursors that may be monitored for a particular type of accident. Nevertheless, a third reason identified during this study is that RUs and IMs often have quite different interpretations of the term 'precursor'. Although different interpretations of the term could be overcome during the interviews, there is some concern that RUs and IMs that provided a response by email may have not provided a full list of their monitoring process due to a different understanding of the term 'precursor'.

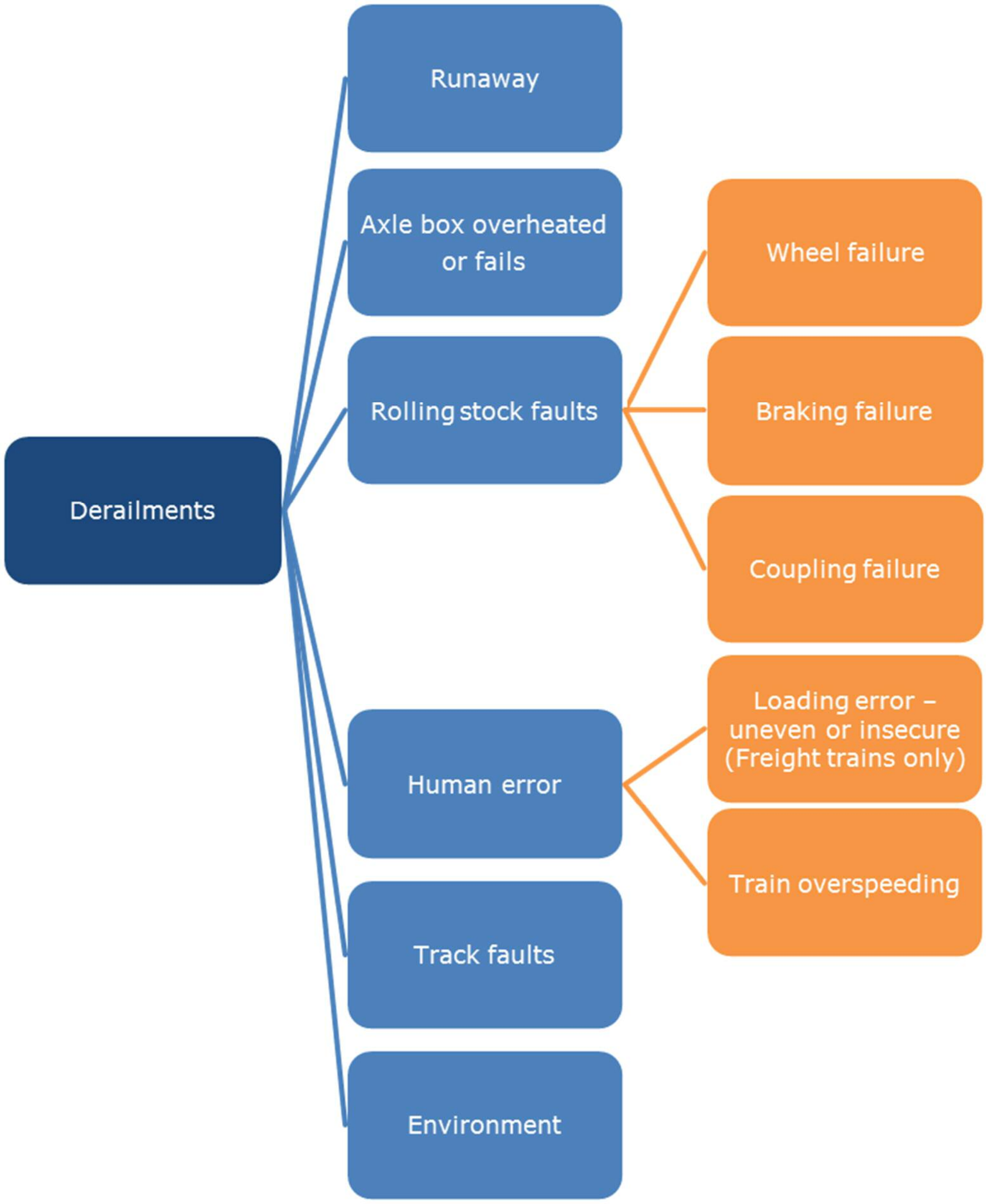
When precursors are monitored at a lower level in the accident causation chain, there are reported benefits to safety due to mitigating actions being more effective (they address hazardous events before any level of hazard is experienced, and for a wider range of accident types) and typically lower cost.

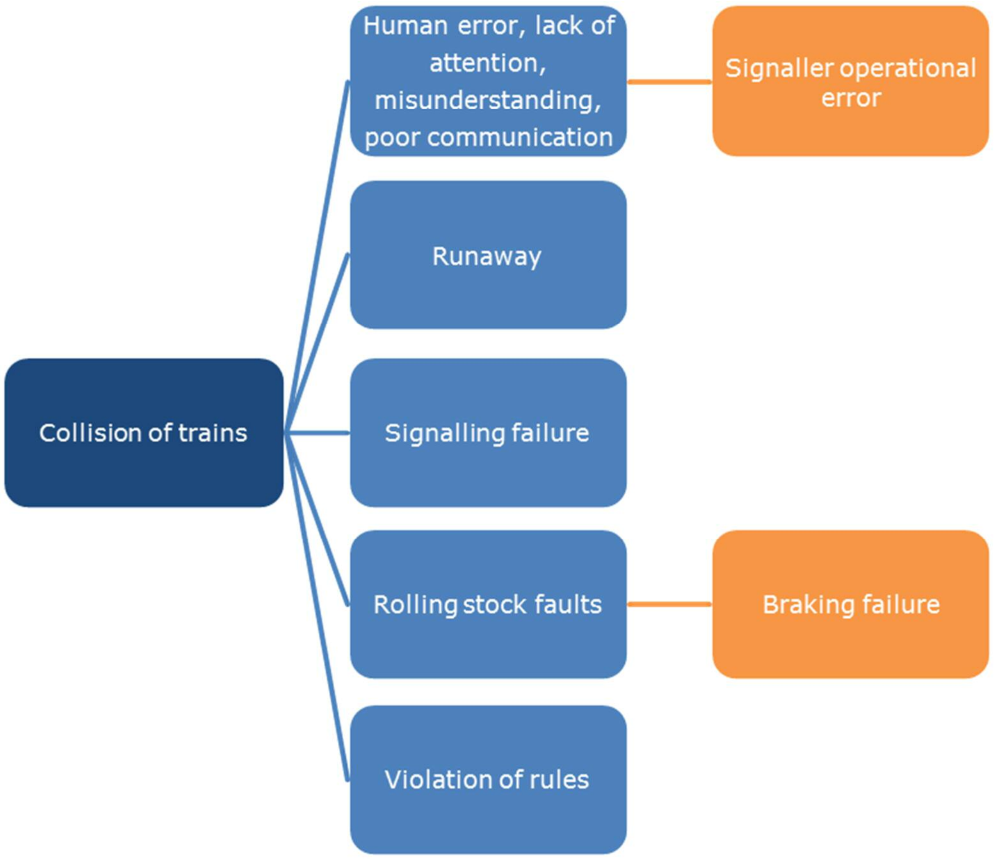
RUs and IMs did report several challenges to precursor monitoring. The challenges experienced were wide-ranging, two of the emerging recommendations for improving precursor monitoring were to focus on greater automation and consolidation of data sources from across an organisation, alongside developing an improved organisational safety culture. With respect to the existing CSI framework of precursors, it was recommended that improvements would follow from further sub-categorisation of each type of the six precursors, with the sub-categories agreed at European level. To follow from this, it was recommended that precursor reporting at European level should reflect the actual safety performance of each member state rather than allowing it to be inferred from raw precursor data that lacks context.

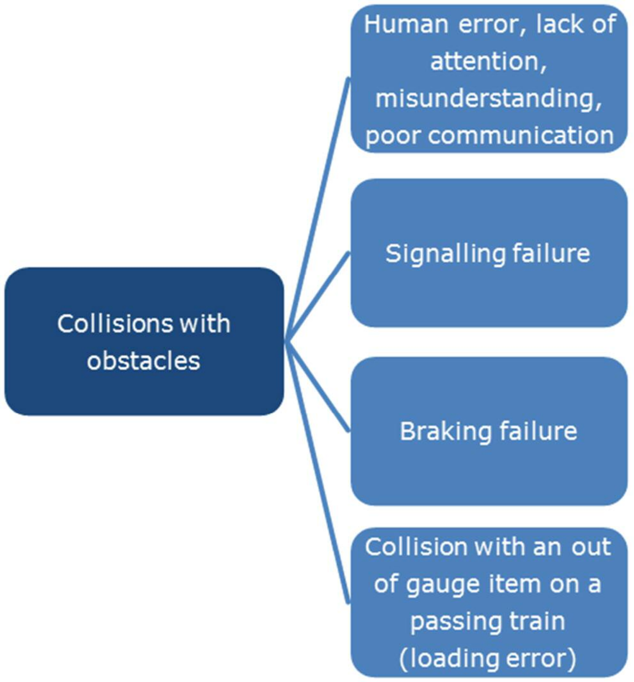
3.4 Priority precursors from Step 2

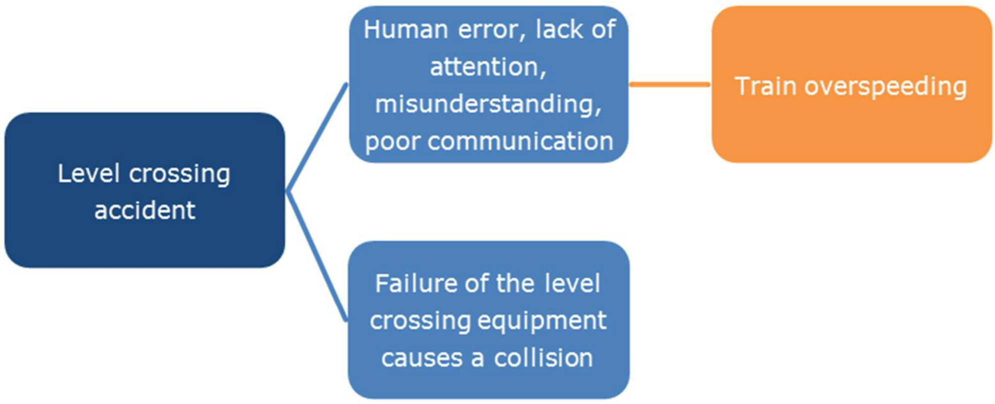
The API was used to establish which precursors are most consistently collected by NSAs, RUs, and IMs, for each of the six accident types. (In this step, derailments were not split by whether they were passenger train or freight train derailments.) Many precursors were gathered by several NSAs, RUs or IMs, the mean of the number of times a precursor was gathered being close to seven, and the mode being six. It was therefore decided that any precursor collected by six or more RU/IMs would be prioritised, though an element of judgement was required to ensure that sub-categories of high frequency categories were also included appropriately. The precursors that met these criteria are presented in a tree format in Figure 10, and in a tabular format in Appendix F. If precursors were to be recommended on the basis of what appears to be practical based on those that are gathered already alone, these would be the precursors recommended.

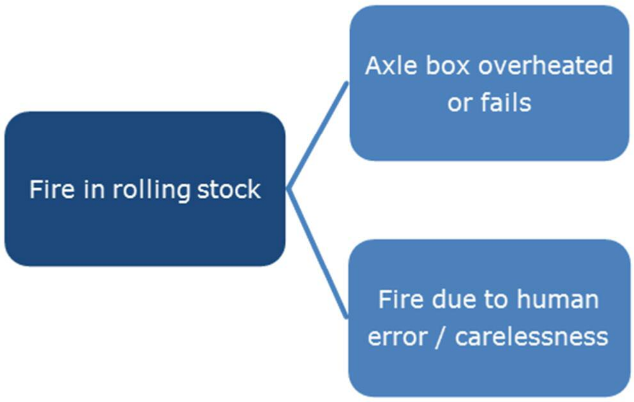
Figure 10: Step 2 Priority Precursors

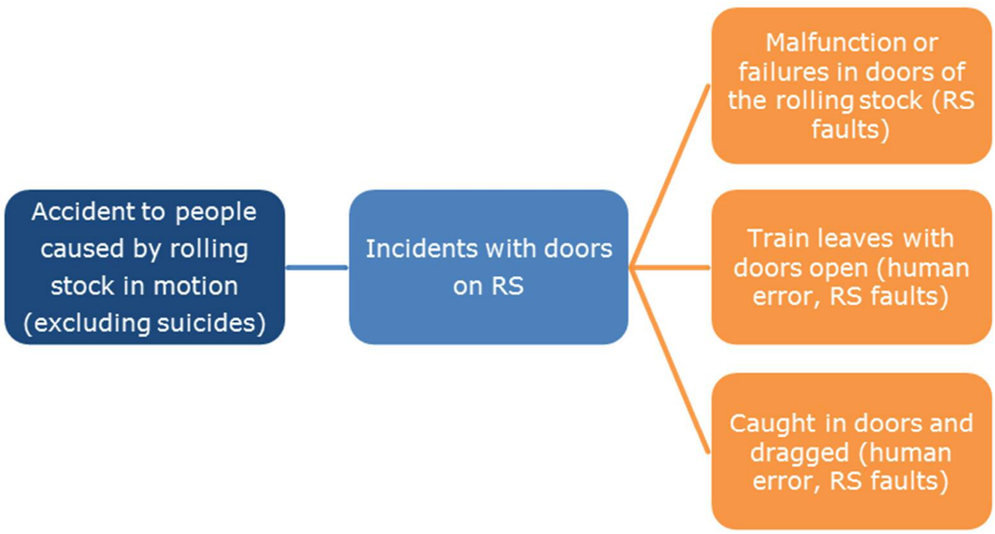



Collision of trains
Human error, lack of attention, misunderstanding, poor communication
Signaller operational error
Runaway
Signalling failure
Rolling stock faults
Braking failure
Violation of rules


Collisions with obstacles
Human error, lack of attention, misunderstanding, poor communication
Signalling failure
Braking failure
Collision with an out of gauge item on a passing train (loading error)


Level crossing accident
Human error, lack of attention, misunderstanding, poor communication
Train overspeeding
Failure of the level crossing equipment causes a collision


Fire in rolling stock
Axle box overheated or fails
Fire due to human error / carelessness


Accident to people caused by rolling stock in motion (excluding suicides)
Incidents with doors on RS
Malfunction or failures in doors of the rolling stock (RS faults)
Train leaves with doors open (human error, RS faults)
Caught in doors and dragged (human error, RS faults)

4 Step 3: Precursor recommendations

4.1 Introduction

Fault trees were constructed for Step 1 of the project based on a theoretical understanding of the role of precursors in accidents. The data available to populate the fault trees included accident data from ERA and UIC and precursor information from European risk models (made available in confidence to inform this project), such as RSSB's Safety Risk Model (SRM). Accident precursors detailed in the fault trees were identified in the literature review and from existing risk models. Precursors with the highest level of contribution to the overall risk of an accident were deemed the most relevant at this point. A list of these precursors can be found in Section 2.7.

The fault trees were updated during Step 2 as a more practical understanding was gained through detailed interviews with European RU/IMs. As stated in Section 3 of this report, the aim of the interviews was primarily to obtain information regarding precursor monitoring practices beyond those established by the RSD. Data from the 19 interviews were translated (when required), collated into the API and classified. From this, a number of commonly monitored precursors in addition to the six CSIs were identified. Precursors were then added to the fault trees where appropriate depending on:

- The type of precursor and the associated accident type
- The clarity of the precursors meaning (particularly with translated information)
- Comparisons with precursors contained in EU data

Following this exercise, fault trees were amended to incorporate European terminology for precursors (e.g. 'broken fishplates' was changed to 'rail fastening and joints').

The API was then used to establish which precursors are most consistently collected by NSAs, RUs and IMs. The accident precursors most commonly gathered by NSAs, RUs and IMs can be found in Section 3.4.

Step 3, reported in this Section, brought these two previous steps together, to develop a harmonised set of precursors that might be a priority for safety management in the future, based on both their theoretical contribution and the practicality of gathering them.

4.2 Precursor selection approach

Those precursors that have a relatively large percentage contribution to the risk of accidents and that are already gathered by many NSAs, RUs or IMs appear to be the most appropriate additional precursors for ERA to recommend gathering routinely as part of the CSIs. As well as having a larger role in accident causation, they would require the smallest amount of additional resource to gather.

Precursors that have a relatively small percentage contribution to accident risks, and that are not routinely gathered at a country specific level are the lowest priority precursors with regards to routine monitoring. Gathering such precursors is likely to require disproportionate effort for the safety benefit that gathering them would provide.

Both risk and frequency of collection help to prioritise which additional precursors might be gathered in the future, though there are clearly other criteria which may also assist with precursor selection, such as those referred to in Section 1.2 and the ability to identify an appropriate normaliser or exposure metric, for example.

4.3 Prioritising based on accident type frequency

Before selecting precursors that might be associated with a given accident type, it is worth considering which accidents are the most common, or are associated with the greatest risk. Identifying precursors that are associated with more common or higher risk accident types is likely to offer more potential to reduce risk than identifying precursors associated with less common or lower risk accident types.

The same precursors may, of course, be common to more than one accident type. For example, a runaway might be a causal factor common to both a signal passed at danger and a train derailment. While the relative frequencies of different accident types and of investigations of different accident types may be informative in terms of precursor prioritisation, therefore, some caution should be applied to prioritising the identification of possible precursors on this basis alone.

Based on the ERAIL database and the UIC database, the frequencies of different accident types appear to be ordered as in Table 18 (based on Table 4 and Table 3). As Table 18 shows, the frequencies with which different accident types are investigated by National Investigation Bodies (NIBs) varies substantially (based on Table 6).

Table 18: Accident type frequency and investigation frequency

Accident Type	Significant accidents (CSIs) in ERAIL-CSI database	Significant accidents in UIC database	Occurrences investigated by NIBs in ERAIL-INV database
1. Accidents to persons caused by rolling stock (excluding suicides)	51%	35%	18%
2. Level crossing accidents	27%	39%	29%
3. Collisions with obstacles	7%	11%	7%
4. Derailments	7%	10%	31%
5. Collisions of trains	6%	3%	10%
6. Fires in rolling stock	2%	2%	5%

The numbers of accidents of each type that are investigated by NIBs do not fully reflect the frequencies of the different accident types themselves. This is because the CSI data contained in the ERAIL and UIC databases comprise all significant accidents, while NIBs focus their investigations on mainly serious accidents (i.e. train collisions and derailments), as well as investigating some non-significant accidents (see Section 2.5.3). The share of significant accidents (reported under CSIs) to all investigated accidents per type is showed in Figure 11.

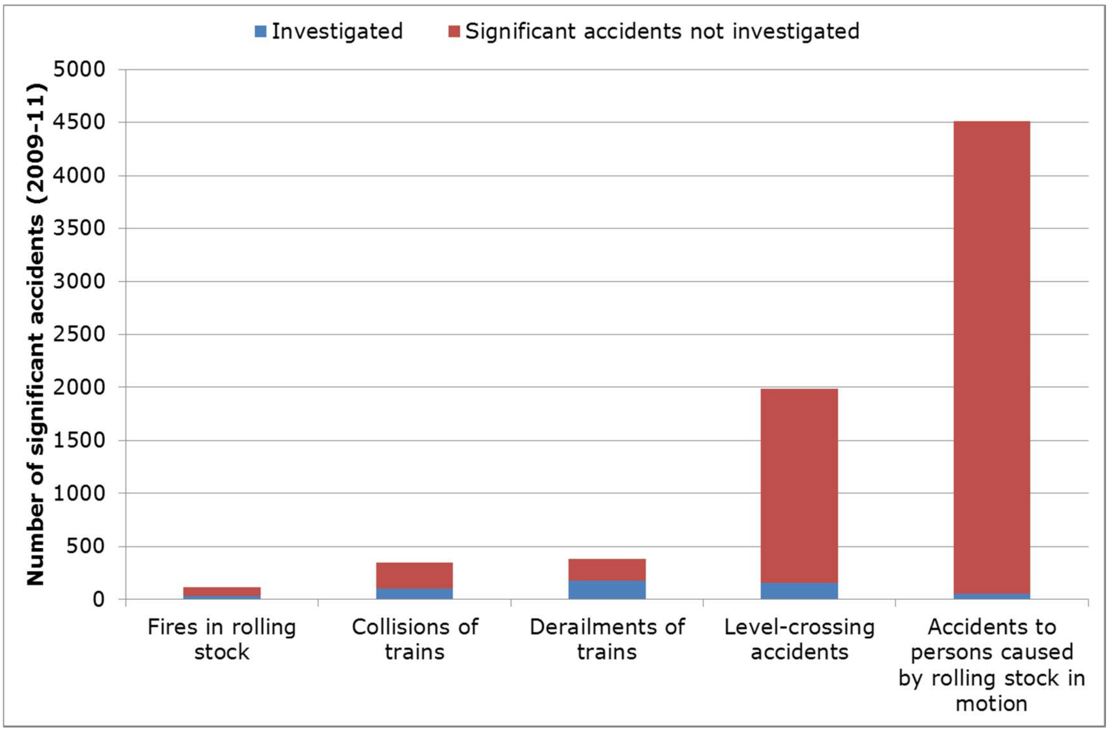


Figure 11: Relative share of significant accidents investigated by National Investigation Bodies (EU-27) (ERA, 2013)

This shows that train derailment is the preferred type of accident into which NIBs open investigations, with 46% of derailment accidents being investigated by NIBs. Less than a third of significant train collisions and fires in rolling stock are investigated by NIBs, and only 8% of level crossing accidents are subject to independent investigation. This seems surprising since, in these accidents, it is thought that the responsibility of IMs for the state of infrastructure is engaged. Establishing causes of accidents to persons caused by rolling stock in motion is usually thought to be straightforward; the investigation into this type of accident is typically limited and carried out by the operations in co-operation with judicial authorities.

4.4 Most commonly gathered precursors

Step 2 identified that the most commonly gathered precursors amongst participating NSAs and RUs/IMs, beyond the six existing CSIs, were:

1. Human error, lack of attention, misunderstanding, or poor communication
2. Runaway
3. Wrong routing
4. Axle box overheated or fails
5. Signalling failure
6. Braking failure
7. Train overspeeding
8. Rolling stock faults

In some cases, multiple levels in the fault trees mean that some of these are lower level precursors of other precursors. For example, train overspeeding may be a type of human error.

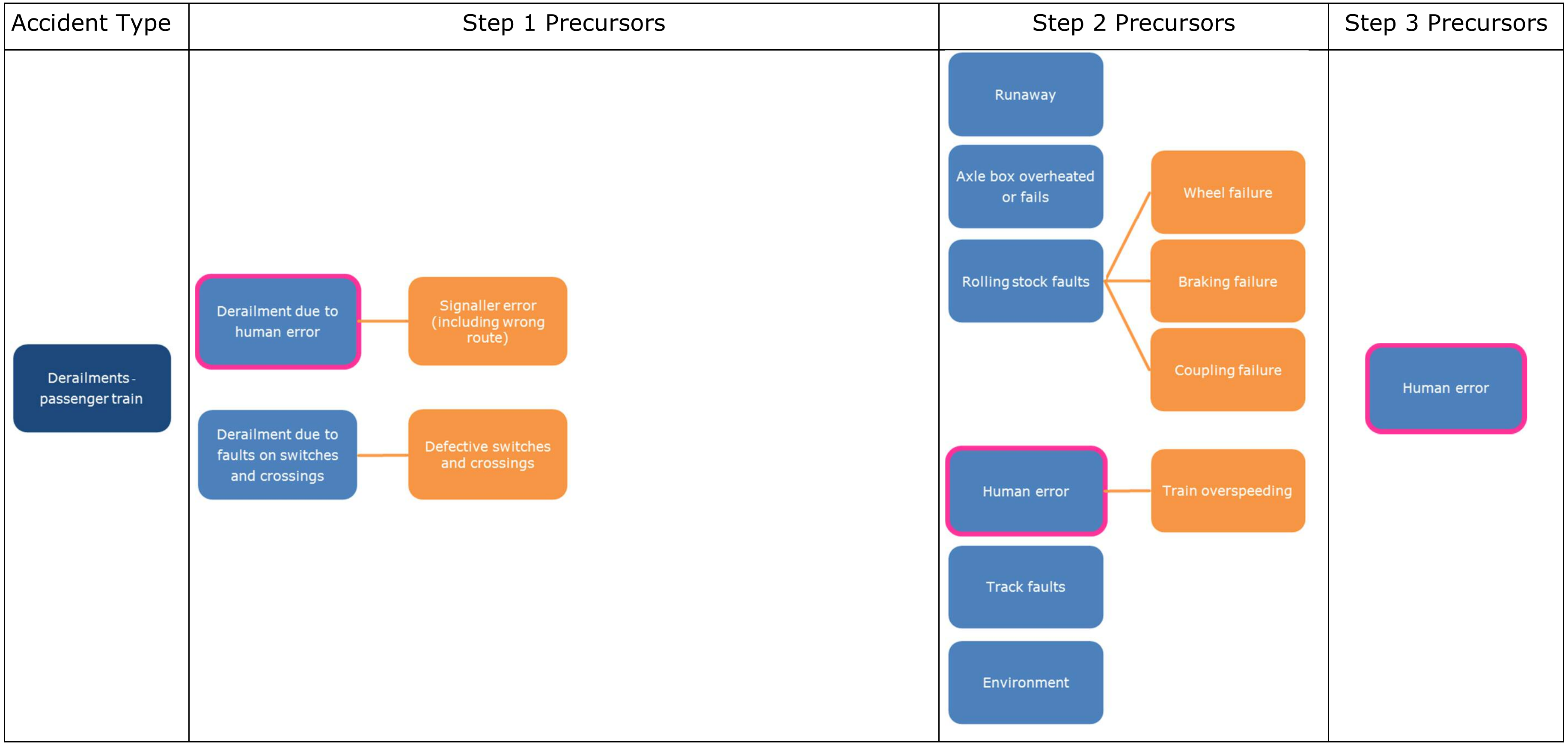
Inclusion of the lower level precursors was considered important given the high frequency of collection of such precursors. In addition, although higher level precursors may be more relevant for safety monitoring at EU level in terms of regulation, lower level precursors would be needed to allow RUs/IMs to use these precursors to improve their operational practices. This is considered further in Section 5.

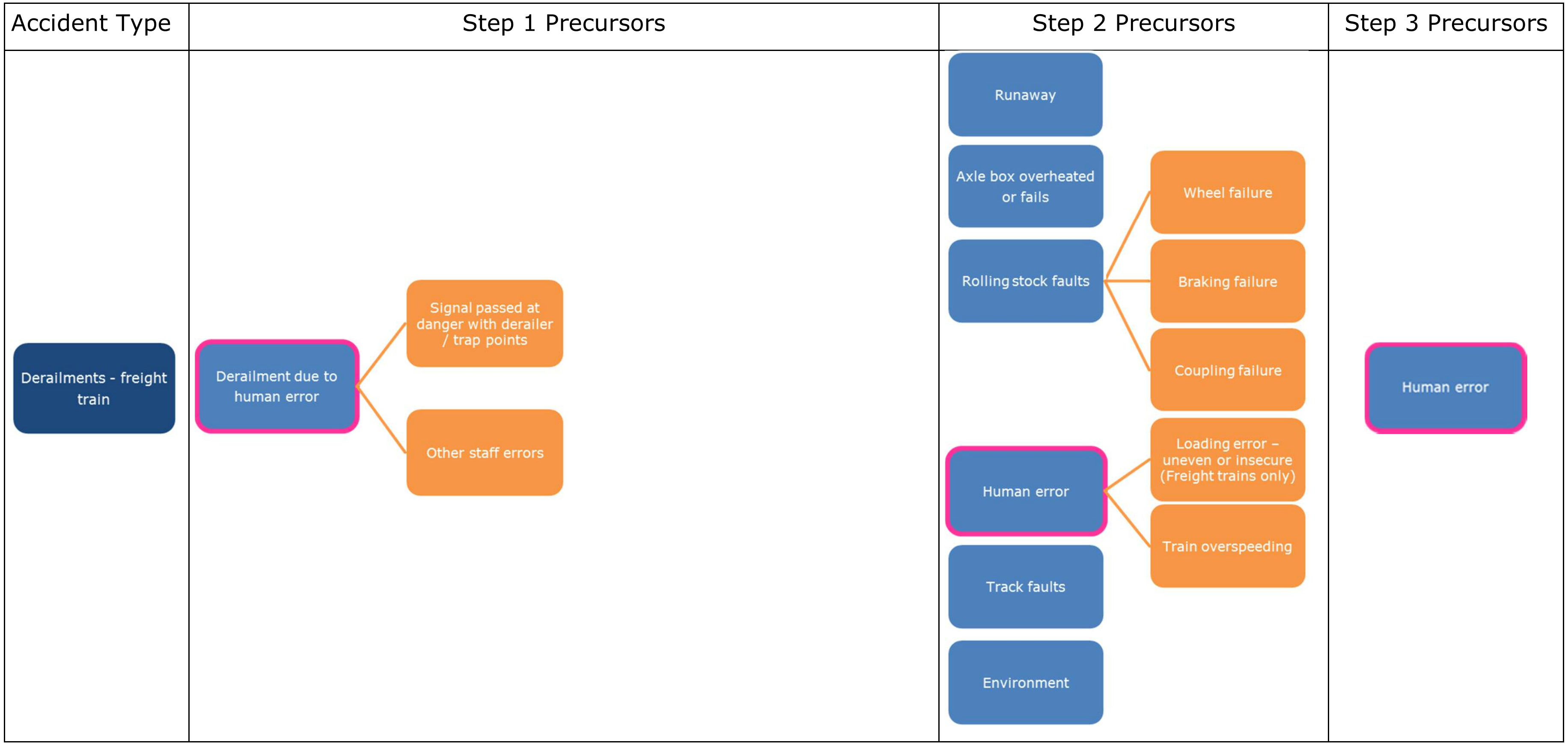
4.5 Recommending priority precursors for each accident type

In the following sub-sections, the commonly gathered precursors associated with each of the six accident types are brought together with their contribution to risk, to identify precursors that might be considered for safety monitoring by RUs/IMs, NSAs and ERA, one accident type at a time.

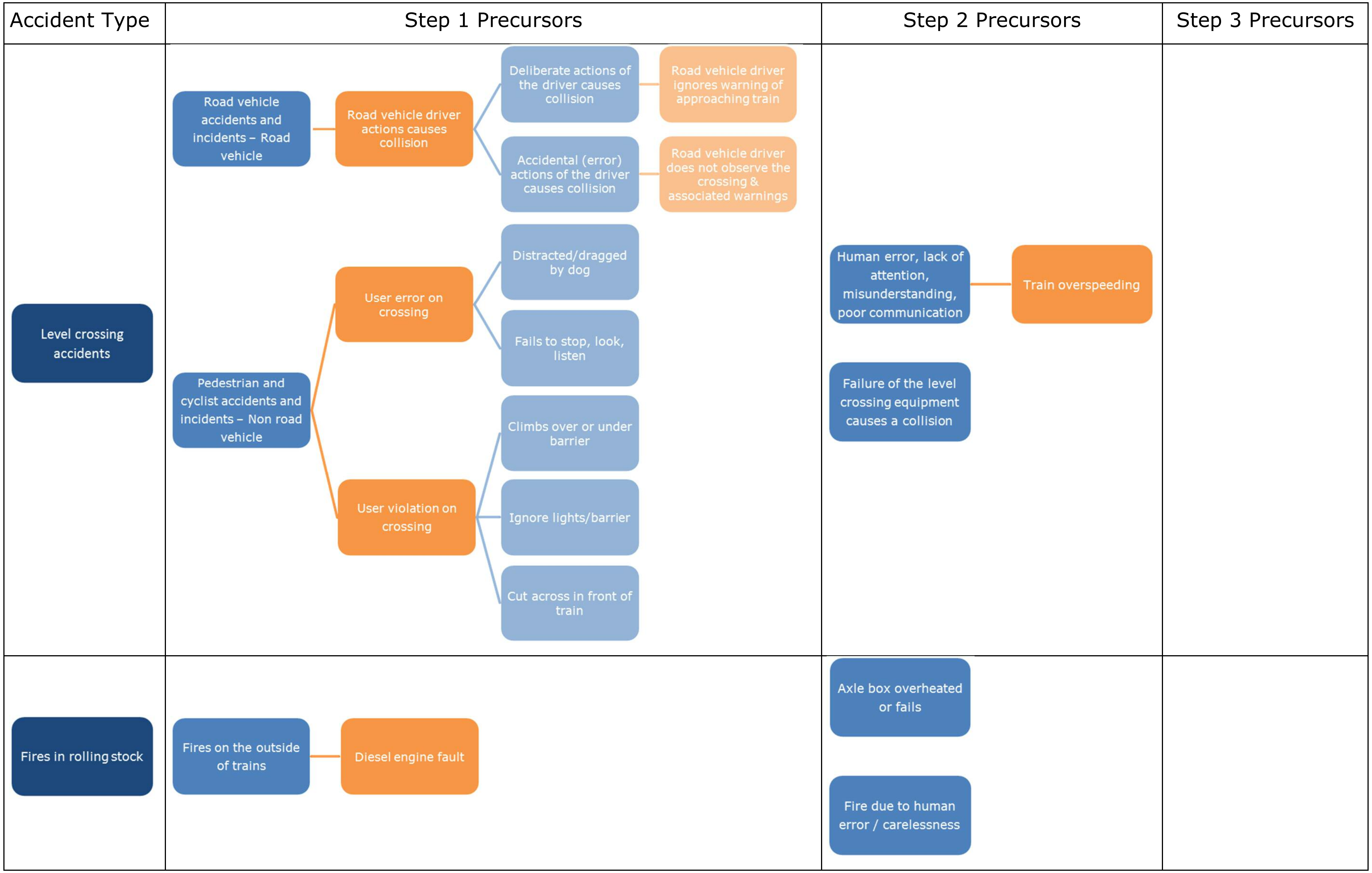
A precursor is recommended for collection if it meets two conditions: firstly, it must contribute 20% or more of the risk for a given accident type; secondly, it must also be practicable to collect, which is indicated by at least five or more respondents from Step 2 reporting its collection. The recommended precursors for each accident type are discussed in the following sections, and Figure 12 presents the process graphically.

Figure 12: Identifying Step 3 Precursors from Step 1 and Step 2 Precursors

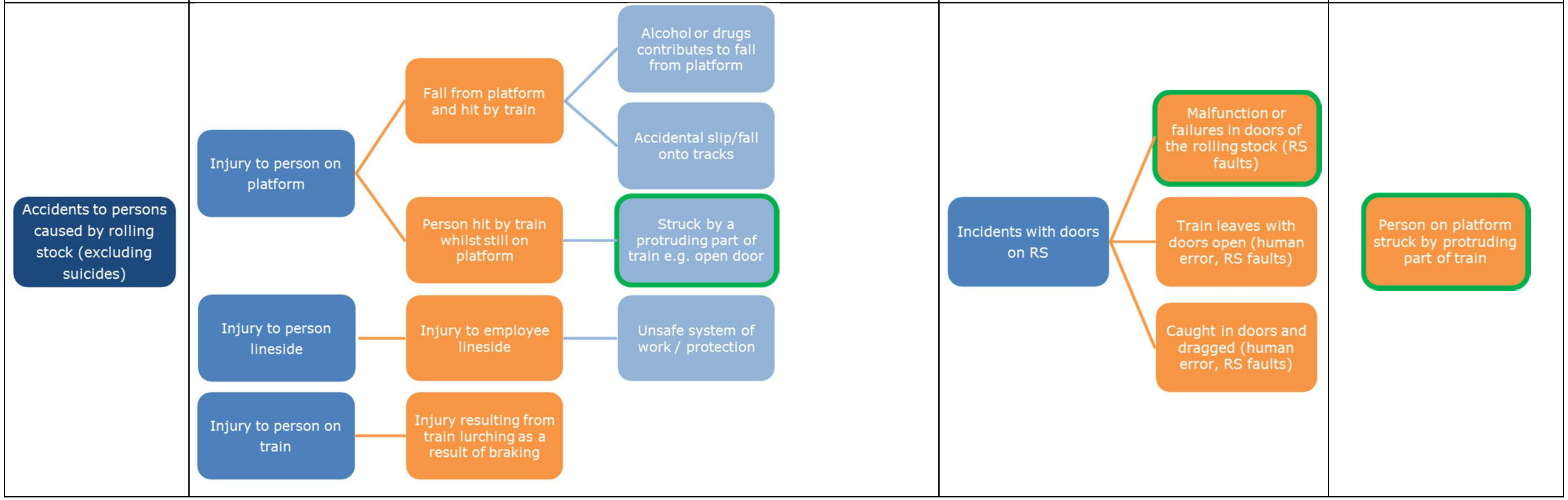



Accident Type
Step 1 Precursors
Step 2 Precursors
Step 3 Precursors
Derailments - freight train
Derailment due to human error
Signal passed at danger with derailer / trap points
Other staff errors
Runaway
Axle box overheated or fails
Rolling stock faults
Wheel failure
Braking failure
Coupling failure
Human error
Loading error – uneven or insecure (Freight trains only)
Train overspeeding
Track faults
Environment
Human error

Accident Type	Step 1 Precursors	Step 2 Precursors	Step 3 Precursors
Collision of trains	Driver error leading to train train collision – Driver fails to check aspect of signal past control point Runaway train	Human error, lack of attention, misunderstanding, poor communication – Signaller operational error Runaway Signalling failure Rolling stock faults – Braking failure Violation of rules	Human error Runaway train
Collisions with obstacles	Collision with items left on the line by vandals Collision with other objects – Collision with road vehicle on the line as a result of a road traffic accident	Human error, lack of attention, misunderstanding, poor communication Signalling failure Braking failure Collision with an out of gauge item on a passing train (loading error)	Collision with other objects


Accident Type
Step 1 Precursors
Step 2 Precursors
Step 3 Precursors
Level crossing accidents
Road vehicle accidents and incidents – Road vehicle
Road vehicle driver actions causes collision
Deliberate actions of the driver causes collision
Road vehicle driver ignores warning of approaching train
Accidental (error) actions of the driver causes collision
Road vehicle driver does not observe the crossing & associated warnings
Pedestrian and cyclist accidents and incidents – Non road vehicle
User error on crossing
Distracted/dragged by dog
Fails to stop, look, listen
User violation on crossing
Climbs over or under barrier
Ignore lights/barrier
Cut across in front of train
Human error, lack of attention, misunderstanding, poor communication
Train overspeeding
Failure of the level crossing equipment causes a collision
Fires in rolling stock
Fires on the outside of trains
Diesel engine fault
Axle box overheated or fails
Fire due to human error / carelessness

Accident Type	Step 1 Precursors	Step 2 Precursors	Step 3 Precursors



As is described in the following sections, unfortunately this approach did not yield many precursors: based on the information available for this study, few precursors were found to be both high risk and commonly gathered. One of the main limitations of this approach is that only limited risk data for each precursor were available. Therefore, it would be useful to consider the value of collecting other precursors that were also reported in Step 2 – even if their contribution to accident risk was not identified in the data as high – because of the variability in risk that is likely to exist in different parts of Europe, that is not reflected in the figures identified in Step 1. Sections 4.5.1 - 4.5.6 tabulate the precursors that appear in the fault trees and were reported by at least one NSA and/or RU/IM in Step 2 for each accident type. These tables present:

- The colour-coded risk level (high, medium, low) for each precursor, as defined in the fault trees. Precursors are ordered according to whether they occur at the first, second or third levels in the fault trees.
- The count of NSA and/or RU/IM that reported collecting each precursor in Step 2.
- An indication of the level at which the precursor should be collected (RU/IM, or NSA and RU/IM). The recommended level of collection is based on whether the precursor was reported in Step 2 by RUs/IMs exclusively, or by NSAs and/or RUs/IMs.

4.5.1 Derailment

4.5.1.1 High theoretical contribution to risk and commonly gathered

In the derailment fault trees, **human error** was the only precursor that was identified as a priority by both Steps 1 and 2. This category includes signaller and driver errors (e.g. overspeeding), as well as other staff errors such as, in the case of freight, uneven or insecure loading; however, only 'signaller error including wrong route' was found to be a high contributor to risk for this particular accident type based on the data available, and this was not commonly gathered by RUs/IMs and/or NSAs.

Interviews with RUs/IMs identified other high collection frequency precursors, such as runaway, rolling stock faults (including braking failure, wheel failure and coupling failure) as well as track faults. Both rolling stock and track faults represent a 'moderate' level of risk on the fault trees, and hence were not included in the Step 1 priority list. Based on the data available, runaway appears to contribute only moderately to the precursor 'derailment due to other causes' which itself represents 5% or less risk to accidents. (However, runaway was a higher priority precursor for collisions of trains – see Section 4.5.2.)

4.5.1.2 Other precursors gathered by sampled NSAs or RUs/IMs – passenger trains

Table 19 shows that 19 precursors were reported in Step 2 and were present in the fault trees for passenger train derailments. Of the four precursors occurring at the first level in the fault tree, two were high risk and two were medium risk. Of the two high risk precursors, 'human error' was the most commonly collected (hence it has been recommended for wider collection). Of the remaining 15 precursors occurring at the second level in the fault trees, five were attributed to 'human error' and can therefore provide some further indication of the types of human errors that it may be worth monitoring on a wider scale. In terms of risk, the highest risk second-level precursor attributed to human error was 'signaller error including wrong route'. In terms of frequency of collection by respondents in Step 2, 'train overspeeding' was the most commonly collected second-level precursor attributed to human error. While this precursor was low risk in the fault trees, it should be noted that careful monitoring of this precursor may have contributed to a reduction in risk over time so it could be worthy of wider monitoring in the European context. The same may apply to 'runaway train' as a precursor; this was the most commonly collected in Step 2 but was relatively low risk for passenger train derailments.

Of the other precursors in Table 19, three types of rolling stock fault were monitored by at least five respondents in Step 2. These faults were 'braking failures', 'coupling failures' and 'wheel failures' (monitored by 10, 6 and 5 respondents in Step 2 respectively).

Table 19: Precursors for passenger train derailments, organised by fault tree risk codes and number of respondents that reported collecting each precursor

Precursor	Risk in fault tree at:		Count	To be collected by:
	1st level	2nd level		
Human error	H		8	NSA & RU/IM
Faults on switches and crossings (S&C)	H	-	3	RU/IM
Rolling stock faults	M	-	10	NSA & RU/IM
Track faults (superstructure)	M	-	6	NSA & RU/IM
Human error - signaller error (including wrong route)	H	H	3	NSA & RU/IM
Human error - track maintenance staff errors	H	M	3	NSA & RU/IM
Human error - shunters errors	H	L	1	RU/IM
Human error - train overspeeding	H	L	6	NSA & RU/IM
Human error - error operating switch or crossing (local control)	H	N/A	1	RU/IM
Rolling stock faults - wheel failure	M	H	5	NSA & RU/IM
Structural failures - bridge bashing leading to bridge collapse	M	H	1	NSA & RU/IM
Track faults - track buckle	M	H	1	NSA & RU/IM
Rolling stock faults - axle failure	M	M	3	NSA & RU/IM
Rolling stock faults - wheel flats or tyre wear beyond limits	M	M	1	RU/IM
Track faults - broken rail	M	M	1	NSA & RU/IM
Rolling stock faults- coupling failure	M	L	6	NSA & RU/IM
Structural failures - bridge bashing leading to bridge displacement	M	L	1	NSA & RU/IM
Rolling stock faults - Braking failure	M	N/A	10	NSA & RU/IM
Runaway	L	M	11	NSA & RU/IM

4.5.1.3 *Other precursors gathered by sampled NSAs or RUs/IMs – freight trains*

Table 20 shows that 20 precursors were reported in Step 2 and were present in the fault trees for freight train derailments. Of the four precursors occurring at the first level in the fault tree, one was high risk and three were medium risk. The high risk precursor was 'human error'. Of the remaining 16 precursors occurring at the second level in the fault trees, six were attributed to 'human error' and can therefore provide some further indication of the types of human errors that it may be worth monitoring on a wider scale. In terms of risk, the highest risk second-level precursor attributed to human error was 'signaller error including wrong route' (as it was with passenger train derailments). In terms of frequency of collection by respondents in Step 2, 'loading error – uneven or insecure' was the most commonly collected second-level precursor attributed to human error. Again, a precursor may be low risk as a result of being widely monitored so it could be worthy of wider monitoring in the European context.

Of the other second-level precursors in Table 20, eight were medium risk at the first level. Of these, 'runaway train' was the highest risk and the most commonly monitored by Step 2 respondents.

Table 20: Precursors for freight train derailments, organised by fault tree risk codes and number of respondents that reported collecting each precursor

Precursor	Risk in fault tree at: 1st level	Risk in fault tree at: 2nd level	Count	To be collected by:
Human error	H		8	NSA & RU/IM
Rolling stock faults	M	-	10	NSA & RU/IM
Track faults (superstructure)	M	-	6	NSA & RU/IM
Faults on switches and crossings (S&C)	M	-	3	RU/IM
Human error - signaller error (including wrong route)	H	M	3	NSA & RU/IM
Human error - Loading error - uneven or insecure	H	L	8	NSA & RU/IM
Human error - train overspeeding	H	L	6	NSA & RU/IM
Human error - track maintenance staff errors	H	L	3	NSA & RU/IM
Human error - error operating switch or crossing (local control)	H	L	1	RU/IM
Human error - shunters errors	H	L	1	RU/IM
Runaway	M	H	11	NSA & RU/IM
Rolling stock faults - axle failure	M	M	3	NSA & RU/IM
Track faults - broken rail	M	M	1	NSA & RU/IM
Track faults - track buckle	M	M	1	NSA & RU/IM
Rolling stock faults- coupling failure	M	L	6	NSA & RU/IM
Rolling stock faults - wheel failure	M	L	5	NSA & RU/IM
Rolling stock faults - wheel flats or tyre wear beyond limits	M	L	1	RU/IM
Rolling stock faults - Braking failure	M	N/A	10	NSA & RU/IM
Structural failures - bridge bashing leading to bridge collapse	L	H	1	NSA & RU/IM
Structural failures - bridge bashing leading to bridge displacement	L	L	1	NSA & RU/IM

4.5.2 Collisions of trains

4.5.2.1 High theoretical contribution to risk and commonly gathered

Human error and **runaway trains** were precursors identified in both steps. The human error precursor included driver error, staff misunderstanding and poor communication.

Step 2 identified a further list of precursors that included 'signalling failure' and 'rolling stock faults' (particularly braking failure). The fault trees indicate that, for this particular accident type, rolling stock faults and signalling failure/error contribute less than 5% of the overall risk.

4.5.2.2 Other precursors gathered by sampled NSAs or RUs/IMs

Table 21 shows that 11 precursors were reported in Step 2 and were present in the fault trees for train-train collisions. Of the six precursors occurring at the first level in the fault tree, one was high risk, two were medium risk and three were low risk. The high risk precursor was 'runaway train', which was jointly the most commonly collected by respondents in Step 2. Of the remaining five precursors occurring at the second level in the fault trees, four were attributed to 'human error' and can therefore provide some further indication of the types of human errors that it may be worth monitoring on a wider scale. In terms of risk, the highest risk second-level precursor attributed to human error was 'violation of rules'. In terms of frequency of collection by respondents in Step 2, 'signaller sets the wrong route' was the most commonly collected second-level precursor attributed to human error.

Table 21: Precursors for collisions with trains, organised by fault tree risk codes and number of respondents that reported collecting each precursor

Precursor	Risk in fault tree at:		Count	To be collected by:
	1st level	2nd level		
Runaway	H	-	11	NSA & RU/IM
Signalling failure (wrong side)	M	-	9	NSA & RU/IM
Miscommunication	M	-	3	NSA & RU/IM
Rolling stock fault	L	-	8	NSA & RU/IM
Environment	L	-	1	RU/IM
Signaller error leading to train collision	L	-	1	NSA & RU/IM
Violation of rules	H	M	6	NSA & RU/IM
ERTMS/ ATP/ ATC data entry error	H	N/A	1	RU/IM
Signaller sets the wrong route	L	H	11	NSA & RU/IM
Braking failure	L	H	8	NSA & RU/IM
Signaller operational error	L	H	7	NSA & RU/IM

4.5.3 Collisions with obstacles

4.5.3.1 High theoretical contribution to risk and commonly gathered

The fault trees identified two main precursors for this accident type: collision with other objects and collision with items left on the line by vandals. The latter, however, can be classed as vandalism, a topic beyond the scope of the present study, and was therefore not considered.

Step 2 identified a number of additional precursors, such as human error, signalling failure, and braking failure for this accident type. However, these were not identified as priority precursors in Step 1 because, in the case of a collision with an obstacle, the failure was considered to be the presence of the obstacle itself, as can be seen in Appendix B. Collision with an out of gauge item on a passing train was also identified through Step 2, which fits this criterion, so the wider category of **collision with other objects** could be recommended.

4.5.3.2 Other precursors gathered by sampled NSAs or RUs/IMs

Table 22 shows that 10 precursors were reported in Step 2 and were present in the fault trees for collisions with obstacles. Of the four precursors occurring at the first level in the fault tree, one was high risk and three were low risk. The high risk precursor was 'collision with other obstacles' – itself a fairly generic precursor. Of the remaining six precursors occurring at the second level in the fault trees, the highest risk was 'collision with RV on the line as a result of a road traffic accident (RTA)', which happens to be a second-level precursor under 'collision with other obstacles'. Therefore, in terms of risk, this precursor would be worthy of consideration for European monitoring.

Of all the precursors for this accident type, the most commonly reported by respondents in Step 2 was 'collision with an out of gauge item on a passing train (loading error)'. It was a low risk precursor in the fault tree. This could be attributed to a reduction in risk over time due to widespread monitoring.

Table 22: Precursors for collisions with obstacles, organised by fault tree risk codes and number of respondents that reported collecting each precursor

Precursor	Risk in fault tree at:		Count	To be collected by:
	1st level	2nd level		
Collision with other objects	H	-	3	NSA & RU/IM
Collision with rolling stock parts - attached or fallen from trains	L	-	2	NSA & RU/IM
Collision with damaged infrastructure	L	-	2	NSA & RU/IM
Collision with maintenance materials and equipment	L	-	2	NSA & RU/IM
Collision with RV on the line as a result of a RTA	H	H	1	NSA & RU/IM
Collision with a person	M	N/A	1	RU/IM
Collision with object due to infrastructure defect or fault	L	H	2	NSA & RU/IM
Collision with objects/ debris fallen from trains	L	M	1	NSA & RU/IM
Collision with an out of gauge item on a passing train (loading error)	L	L	4	RU/IM
Collision with maintenance vehicle left foul of the line	L	L	1	NSA & RU/IM

4.5.4 Level crossing accidents

4.5.4.1 High theoretical contribution to risk and commonly gathered

Building on the research by Elliott (2008) discussed in Section 2.2.2, Step 1 identified two categories of precursors:

- road vehicle accidents and incidents, which tend to result from road vehicle driver errors, and
- pedestrian and cyclists accidents and incidents, which tend to result from user error.

Although IMs may be able to take measures that mitigate the effect of violations and road user errors, such as installing equipment or increasing visibility, road vehicle driver and other road user errors are not specifically within the remit of railway operators. This is reflected in the precursors that are gathered for this accident type: the most frequently collected precursors relate to human errors by train drivers and failures of the level crossing equipment itself. Given these differences, no precursors relating to level crossing collisions can be recommended on the basis of commonly collected precursors having a high accident risk according to available data.

4.5.4.2 Other precursors gathered by sampled NSAs or RUs/IMs

Table 23 shows that 17 precursors were reported in Step 2 and were present in the fault trees for level crossing accidents. Of the four precursors occurring at the first level in the fault tree, the risk level was known for two precursors only, which were high risk. They were 'road vehicle accidents and incidents' and 'pedestrian and cyclist accidents and incidents'. The precursors occurring at the second and third levels in Table 23 provide more detail to support these two high risk first-level precursors. Specifically, six of the remaining 13 precursors were associated with 'road vehicle accidents and incidents':

- Four of these precursors occurred at the second level in the fault tree. 'Road vehicle driver action causes collision' was the highest risk. 'Failure of the level crossing equipment causes a collision', 'road vehicle failure causes collision' and 'environmental factors cause a collision' were given the same, lower risk rating (and have been listed in order of how commonly they were collected by respondents in Step 2, from high to low).
- Two of these precursors occurred at the third level in the fault tree. Of these, the higher risk precursor was 'equipment failure - lights and/or barriers fail to operate resulting in a collision' (which is a third-level precursor for 'failure of the level crossing equipment causes a collision'). The lower risk third-level precursor was 'environmental - ice and snow on the road prevent a road vehicle from stopping' (which is a third-level precursor for 'environmental factors cause a collision').

Two of the remaining 13 precursors were associated with 'pedestrian and cyclist accidents and incidents'. Both were high-risk, second-level precursors ('user error on crossing' and 'user violation on crossing').

Table 23: Precursors for level crossing accidents, organised by fault tree risk codes and number of respondents that reported collecting each precursor

Precursor	Risk in fault tree at: 1st level	2nd level	3rd level	Count	To be collected by:
Road vehicle accidents and incidents	H	-	-	3	NSA & RU/IM
Pedestrian and cyclist accidents and incidents	H	-	-	2	NSA & RU/IM
Human error - train overspeeding	N/A	-	-	6	NSA & RU/IM
Signal passed at danger	N/A	-	-	1	RU/IM
Road vehicle driver action causes collision	H	H	-	2	NSA & RU/IM
User error on crossing	H	H	-	1	NSA & RU/IM
User violation on crossing	H	H	-	1	RU/IM
Failure of the level crossing equipment causes a collision	H	M	-	4	NSA & RU/IM
Road vehicle failure causes collision	H	M	-	3	NSA & RU/IM
Environmental factors cause a collision	H	M	-	2	NSA & RU/IM
Workforce error leading to pedestrian/ cyclist injury	H	L	-	2	NSA & RU/IM
Gates left open	H	H	M	1	RU/IM
User violation - unauthorised use	H	H	L	1	RU/IM
Equipment failure - Lights and/ or barriers fail to operate resulting in a collision	H	M	M	2	NSA & RU/IM
Equipment failure - Crossing equipment fails to detect approaching train resulting in a collision	H	M	M	1	NSA & RU/IM
Proper use made of crossing - Train undetected or lights fail	H	M	L	1	NSA & RU/IM
Environmental - Ice and snow on the road prevent a road vehicle from stopping	H	M	N/A	1	NSA & RU/IM

4.5.5 Fires in rolling stock

4.5.5.1 High theoretical contribution to risk and commonly gathered

Fires on the outside of trains and, in particular, those resulting from diesel engine faults, were identified as the priority precursors in Step 1 (i.e. coded as 'red' in the first and second levels of the fault tree, indicating that they account for 20% or more of the respective risk at each level). On the other hand, axle box overheated or fails and fire due to human error / carelessness were identified as the priority precursors from Step 2. These differences suggest that there are no suitable precursors for this accident type which can be recommended on the basis of their high contribution to risk and being commonly gathered.

4.5.5.2 Other precursors gathered by sampled NSAs or RUs/IMs

Table 24 shows that six precursors were reported in Step 2 and were present in the fault trees for fires in rolling stock. There are no precursors that are recommended as high priority for collection (i.e. coded as red for both levels in the fault tree and collected by at least five different respondents). However, Table 24 indicates other precursors that may be worth considering. Specifically, 'axle box overheated or fails' and 'other faults/failures results in fires' are two precursors that are high-medium risk and were collected by several respondents in Step 2.

Table 24: Precursors for fires in rolling stock, organised by fault tree risk codes and number of respondents that reported collecting each precursor

Precursor	Risk in fault tree at: 1st level	Risk in fault tree at: 2nd level	Count	To be collected by:
Axle box overheated or fails	H	M	11	NSA & RU/IM
Other faults/ failures results in fire	H	M	3	NSA & RU/IM
Other mechanical failure leads to train fire	H	L	2	RU/IM
Other electrical faults leads to train fire	H	L	1	RU/IM
Fire due to human error/ carelessness	M	H	5	NSA & RU/IM
Fire due to electrical equipment failures	M	M	2	NSA & RU/IM

4.5.6 Accidents to people caused by rolling stock

4.5.6.1 High theoretical contribution to risk and commonly gathered

For this accident type, Step 1 identified human errors as the priority precursors, with two exceptions: person on platform struck by a protruding part of train (i.e. extending beyond the clearance gauge) e.g. open door, or loose part, and injury to person on train resulting from train lurching as a result of braking.

Step 2 identified a more specific type of incident related to doors on rolling stock. The latter can be caused by either human or technical causes, for example 'malfunction or failure in doors of rolling stock', 'train leaves with doors open', and 'caught in doors and dragged'.

Given the overlap between the priority precursors from the two steps, the most appropriate precursor appears to be **person on platform struck by protruding part of train**. This would fall under 'other persons killed and injured' as defined under the CSIs.

4.5.6.2 Other precursors gathered by sampled NSAs or RUs/IMs

Table 25 shows that 11 precursors were reported in Step 2 and were present in the fault trees for accidents to people caused by rolling stock in motion. Of the precursors listed in Table 25, three occupy the first level of the fault tree, three occupy the second level and five are third level precursors. Where risk data are available, all except 'struck by flying object' are considered high risk at each relevant level in the fault tree.

Table 25: Precursors for accidents to people caused by rolling stock in motion, organised by fault tree risk codes and number of respondents that reported collecting each precursor

Precursor	Risk in fault tree at:			Count	To be collected by:
	1st level	2nd level	3rd level		
Injury to person on platform	H	-	-	2	NSA & RU/IM
Injury to person line side	H	-	-	2	RU/IM
Injury to person on train	H	-	-	1	RU/IM
Person hit by train whilst still on platform	H	H	-	1	RU/IM
Caught in doors and dragged	H	N/A	-	1	RU/IM
Injury to person due to poor ride quality	H	N/A	-	1	NSA & RU/IM
Struck by a protruding part of train	H	H	H	2	NSA & RU/IM
Unsafe system of work/ protection	H	H	H	2	NSA & RU/IM
Accidental slip/ fall onto tracks	H	H	H	1	RU/IM
Attempting to retrieve item or cross tracks (not suicide)	H	H	N/A	1	NSA & RU/IM
Struck by flying object	H	L	L	2	RU/IM

4.5.7 Discussion

The precursors identified for derailment and collision of trains show many similarities in terms of the theoretical knowledge of accident causation and the practicality of collecting information on these precursors. This is particularly so in the case of derailment, as all of the frequently collected precursors are clearly represented within the fault trees. This may well be because derailments are one of the highest consequence accident types, and so are the focus of much research (e.g. DNV, 2011).

However, this is somewhat different for collisions with obstacles, level crossing accidents, and accidents caused by rolling stock in motion. These accident types have a higher number of human error-related causes, and hence are subject to more variability and subjectivity in monitoring practices. This point is best illustrated by the ERAIL database, specifically regarding accidents and incidents investigated by NIBs (see Sections 2.5.3.3 and 2.5.3.4 for details). The accident causality information in this database includes 'direct and immediate causes' and 'underlying causes', both of which could be explored to extract relevant precursors, as was attempted in Section 2.5.3.5. However, these used to be free text fields, and it is ambiguous as to the information each category might include, meaning that these fields could not be used systematically even when they are populated. This may be because, particularly in the case of human factors, it can be challenging to identify which are immediate causes and which are underlying causes.

Similarly, at the organisational level, some may choose to follow a 'bottom up' approach (best illustrated by the GEMS model discussed in section 2.3.6), while others may focus on the more easily traceable cause of an accident as this may require less resource to investigate. For example, a collision with an object on the track could be construed as being caused by a human error (someone making a mistake that led to the object being on the track), or the immediate presence of the object (a collision with a road vehicle on the line). The variability in the findings from the interviews shows that some RU/IMs take a bottom up approach to prevent the human factor that caused the object to be on the line, for example, whereas the focus in the primary fault paths in Step 1 was to identify the immediate causes.

4.5.8 Summary

Bringing together Steps 1 and 2 identified just five precursors that should be considered by the European rail industry and authorities, on the basis of their being both theoretically sound and practical to gather, these being:

- Derailment – human error
- Collision of trains – human error
- Collision of trains – runaway trains
- Collision with obstacles – collisions with other objects
- Accident to people caused by rolling stock – person on platform struck by protruding part of train

Combining high risk contributing precursors and precursors that are frequently gathered yielded fewer results than anticipated. Consideration was given to whether it is appropriate for individual precursors to be disregarded on the basis of their not being commonly gathered. It is possible that precursors may contribute more to the overall risk because they are not commonly gathered. Similarly, it is possible that the level of risk associated with a precursor has already been reduced to a low contribution category as a direct result of the precursor being monitored and effectively managed. The outcome of the research in this study significantly develops the thinking in this field for the first time.

4.5.9 Meaningful use of identified precursors

For the derailment – human error precursor, there are differences further down the fault trees in terms of those precursors which are currently gathered and those which contribute a larger share of risk. For example, for passenger train derailments, train overspeeding is commonly gathered, and for freight train derailments, loading error – uneven or insecure is commonly gathered, but the evidence suggests that both of these are only small contributors to risk.

Similarly, for collision of trains – human error, driver fails to check aspect of signal past control point is the largest theoretical contributor, but this relatively detailed precursor is not commonly collected. However, this does not mean that such errors are not collected by individual RUs/IMs; it may just represent a variety of different terminologies or classifications. Collision of trains – runaway trains, on the other hand, is common to both steps, and is also reasonably clear and unambiguous, so it is recommended that this precursor is collected more widely.

For collisions with obstacles – collisions with other objects, again there are differences between what is currently gathered and what is considered to be a large contributor to risk. Collisions with road vehicles on the line as a result of a road traffic accident are the theoretically highest risk subset, whereas only a subset of collisions with miscellaneous objects on the line – those of out of gauge items – is currently gathered.

Accident to people caused by rolling stock – person on platform struck by protruding part of train, is common to both steps, and is also reasonably clear and unambiguous, so it is recommended that this precursor is collected more widely.

In summary, there are two precursors which appear to be theoretically sound, practical to gather, and reasonably clear and unambiguous:

- Collision of trains – runaway trains
- Accident to people caused by rolling stock - person on platform struck by protruding part of train

While the former could be developed into a precursor as it could be considered a causal factor, the latter is a sub-category of an accident type. This may suggest that ERA's focus should be on what are effectively lagging indicators rather than leading indicators, a point that is considered in more detail in Section 5.

The suggested definition of a runaway train, based on the definitions provided to the study team is:

> *A train that ends up in an uncontrolled motion due to a lack of brake mass or mistakes in action with the train brake using maximum retention, such that it cannot be stopped in the stopping distance for the section.*

The suggested definition of a person on platform struck by protruding part of train based on the information provided to the study team is:

> *A person on a railway platform is injured as a result of being hit by loose parts of the train load due to the motion of the rolling stock.*

Both these precursors should be gathered by RUs/IMs and the relevant NSA. There may be some benefit to these being reported to ERA, depending upon what ERA would do with this information; Section 5 discusses this in more detail.

4.5.10 Further considerations

The other three precursors in the shortlist above may warrant further investigation by NSAs and RUs/IMs depending on local circumstances. For example, under the derailment – human error precursor, train overspeeding may be a bigger contributor to risk in a particular circumstance than was identified in this work. It is worth emphasising once again that this work considered average risk and could not take into account all local circumstances: trains equipped with automatic brake systems, for example, may be less likely to overspeed than those without, but this work aggregates both types together.

The quite substantial differences between railways depending on their local circumstances is emphasised in Eksler (2013) which, in reporting of the precursors monitored by NSAs, found that "the indicators are very much country-specific and it is rather difficult to find common patterns among countries". For this reason, it may be informative for all NSAs, RUs and IMs to consider the longer lists identified in Step 1 (see Figure 7 or Appendix C) and Step 2 (see Figure 10 or Appendix F) to identify additional precursors that may be informative in their particular context, rather than relying solely on those in the shortlist identified here in Step 3. It would theoretically be possible to prioritise these on the basis of their contribution to risk and how often they are currently gathered, as identified in this study. However, to be reliable, this approach would require more robust data, both in terms of risk contribution and in terms of the frequency with which precursors are currently gathered. Instead, it is recommended that NSAs, RUs and IMs consider which precursors of those presented in the constituent parts of this study are most relevant for monitoring, based on their detailed knowledge of their particular operational context.

5 The future of precursors

5.1 The purpose of indicators

It is sometimes said that "You manage what you measure"; in reality, of course, proactive management is much more sophisticated than this: the measurement of objective data is necessary for effective management, but effective management requires more than this. Different indicators are complementary to one another; for example, some indicators are forward-looking, or leading, and allow proactive management whereas others are backward-looking, or reactive, and hence more reliable and meaningful as an indicator of performance, but perhaps less usable for proactive management itself.

In the case of railway safety, precursors are often a forward-looking, proactive indicator, key to identifying or anticipating the likelihood of accidents, whereas accident numbers themselves are a necessary indicator of the actual safety performance. Indicators are a management tool that can help manage safety or that can be used for legal enforcement; however, these are not the same objective, and distinguishing between the two is critical.

If used to judge the relative safety performance of different countries' railway networks, for example, precursors must be reliable and relevant, must be based on accurate and comparable data, and need to be appropriately scaled for the size of the network.

The current CSIs capture only a small part of accident causation mechanisms, and other precursors may well be helpful. Their careful selection is critical to ensuring that they do not distort performance or detract from other activities that contribute to improving safety. The use of appropriate precursors is likely to improve both the operational performance and safety performance of an RU or IM – these are complementary rather than at odds with one another. This is to say that the gathering of appropriate precursors will often be commercially driven, rather than regulation being required to ensure they are gathered.

The current CSIs concentrate on technical faults, although Step 1 of this study indicates that most errors tend to be human faults or organisational faults. It is important to understand:

- Why is it desirable to gather specific safety indicators?
- What is the intention for using the gathered information?
- What should the safety indicators look like to align with their purpose and usage?

Recommendations from RUs and IMs for precursors at a European level show a desire for greater sub-categorisation of precursors than is the case with the current CSIs if they are to be used operationally – lower level precursors are a preferred target for monitoring and taking mitigating action.

Although the rail industry can clearly learn from the aviation industry, some comparisons are misplaced: the aviation industry is widely thought of as having been developed in a harmonised way. The rail industry, however, has evolved in a variety of different ways under several completely separate regulatory models. There are, of course, numerous similarities between different railway systems, but harmonising railway safety management in a common framework is inevitably going to take time and is likely to rely on co-operation at least as much as it might rely on obligation.

There is therefore a need to ensure that there is a good 'safety culture' across the rail industry. In the aviation industry, a spirit of open reporting has often been encouraged. The reporting of incidents must not be punished, but must be used to help facilitate the sharing of best practice. Gaining a clear understanding of safety culture, and how to facilitate it, is something that requires further consideration.

5.2 The distinction between regulatory and management indicators

The above discussion suggests that a clearer distinction might be required between regulatory indicators and management indicators. Considering these in turn:

5.2.1 Regulatory indicators

The Railway Safety Directive says that "CSIs have been established in order to assess whether systems comply with the CSTs and to facilitate the monitoring of safety performance." This means monitoring at the member state level by ERA. The indicators are therefore to support regulation and potentially enforcement. This is one specific and highly specialised use of indicators. This use lends itself to a small number of 'lagging' or 'outcome' indictors that have consistent meaning across member states – essentially some sort of benchmarked accident statistics. There should not be a desire to overcomplicate these indicators as the more detailed they are the more flawed they will be for this purpose: more complication will be caused by the particular member state railway context or incident normalisation issues. The value of these indicators is in their providing clear indications of when safety performance at the member state level has changed. As regulation is not a generally a day-by–day activity it does not matter so much if they are quite lagging. The current CSTs do not appear to warn regulators about problems that are emerging. However, the identification of emerging problems should primarily be conducted by active management rather than by regulation.

5.2.2 Management indicators

Within the context of a safety management system, indicators are used to monitor the actual on-going safety performance of an organisation. This needs to be more proactive and targeted at the actual process and outputs of the business. The indicators to use are much more numerous and should incorporate a number of more 'leading' or 'activity' indicators. There needs to be flexibility in which indicators to use for this purpose, and their use may be discontinued from time to time, to facilitate the use of new indicators. That is, different players may benefit from using different precursors at different times.

From a safety management perspective, it might be useful to benchmark some of these indicators if companies routinely collect the same ones, but this benchmarking should be about sharing good practice between companies, and not about regulation or enforcement action at the member state level.

In terms of management indicators, the regulator's role should be in looking at the processes for developing and using these types of indicators rather than the definition of specific indicators. The process for developing and using management indicators is the territory of the CSM on monitoring.

5.2.3 Differences between the two types of indicator

Confusing the two types of indicators could cause the following:

- If management indicators are seen as something that ERA and NSAs are intimately involved in, it might be difficult to encourage companies to develop a strong safety culture and good practice in the use of indicators, as this necessary cultural change could be affected by fears of regulatory response/enforcement. Changes in the reporting culture in the UK have been strongly supported by the fact that RSSB, which facilitates a significant aspect of the reporting, is not a regulatory body, but is part of the industry. The trust has taken a long time to build.

- Safety management is clearly the responsibility of the RU/IM so ERA should be wary of developing indicators at too low a level as they then start defining or placing constraints on the safety management system of the RU/IM which means they must in turn be taking some responsibility for it.
- If more precursor indicators are mandated at EU level by ERA, it might be harder for those with a poor record of safety reporting to appreciate that, regardless of what the regulator requires, they should be doing their own work to develop indicators within their own safety management system.

This emphasises once again that there must be clarity around different types of indicators, how they are used and why. The CSI Annex 1 indicators, which are regulatory indicators, could be updated but it is recommended that these remain at a high level. It might also be advisable for the EU to provide reassurance that it has no intention to continually develop more and more detailed indicators of this type to mandate upon the industry, so that the industry is not discouraged from further developing safety culture.

On the other hand, some companies have a long way to go in the development and use of indicators within their safety management system and no company should assume that the CSIs are the only indicators they should be collecting and monitoring. A summary of good practice in this area, and proposals for helping the industry to develop its practice and culture in the use of indicators as part of their safety management system is provided in a recent RSSB research project 'Measuring Safety Performance' (2011).

5.3 What harmonisation might mean

At one level, harmonisation could mean mandating the reporting of information according to common definitions (as per the CSIs), which makes sense for regulatory indicators. At another level, it could mean harmonising the framework/process for performance monitoring but not proposing specific indicators: this could apply to management indicators and it could be argued that the CSM for Monitoring has been developed with a view to assuring this function, non-specific as it is.

Between those levels, there is potential value in at least moving towards using a common language and way of thinking about / categorising incidents and their causes. Although ERA does not have a database behind the CSIs, UIC does have a safety database which operates on a voluntary basis at the RU/IM level. The UIC safety database is aligned with CSI definitions and also contains additional information on accident causes, but do not indicate the level of risk associated with a particular cause.

5.4 Why gather precursors

Potential reasons why regulatory indicators should be collected include the following:

- To provide confidence that safety in each member state is at least being maintained (i.e. monitor performance against the CSTs/National Reference Values). This is the primary purpose of the CSIs.
- To benchmark performance between member states. This is difficult to do with precursor information for the reasons discussed already. A more meaningful type of benchmarking

could perhaps be made between lines of similar nature in different countries, but that would involve collecting more detailed data.

- To set a minimum standard for NSAs in relation to their data collection and monitoring activity. There are different levels of safety maturity in Europe's railways. While in many states, CSI data collection can be considered a burden that does little to improve national regulation or safety management, this might not be the case everywhere.

One problem with the CSTs – at least for the smaller and/or safer member states – is that they are not sufficiently holistic or robust to provide a good understanding of whether safety is being at least maintained, i.e. they barely serve their primary purpose. The CST assessment might be improved, though will necessarily be limited given it is based purely on injuries in serious accidents. ERA may have wanted to investigate precursors to obtain a better understanding of how safety is maintained within each state: precursor data may be more robust statistically, albeit imperfectly correlated with risk.

5.5 The role of ERA

TRL understands that ERA is currently assessing the safety monitoring framework at the EU level. The recast of the Railway Safety Directive extends the requirement to ensure that railway safety is generally maintained and, where reasonable practicable, continuously improved, from member states to ERA. This means that ERA may assume certain level of responsibility for railway safety in member states. Thus the reactive monitoring through regulatory indicators may not suffice and may have to be combined with proactive monitoring through safety management indicators. This could be concerning given the importance of the distinction between regulatory and safety management indicators. It is suggested that the ultimate aim should be to ensure that the system is properly monitored at operational level and that the authorities (NSA/ERA) have a good understanding of the safety performance of RUs/IMs. The role of the NSA/ERA may ultimately go beyond them being the regulatory watchdogs but it may require great care to ensure that there is not a conflict between:

- ERA's regulatory and operational management roles, and
- the roles of ERA, of NSAs, and of RUs/IMs.

5.6 Recommendations for the future

The focus of this project was to identify additional precursors that could be recommended for monitoring by ERA, by NSAs and/or by RUs/IMs, and some additional precursors that may be useful have been identified. The ways in which precursors are currently used, and how their use could be further developed has also been considered. There are vast differences between the way in which railways are currently managed across Europe, even though a substantial number of NSAs, RUs and IMs currently use precursors for operational reasons. In addition, there appears to be a lack of clarity about the purpose of precursor collection by ERA as specified by legislation, and it is recommended that ERA give much further thought to this matter, in consultation with NSAs, RUs and IMs.

Many NSAs, RUs and IMs need to be encouraged to develop their own systems of precursor monitoring, at a suitably detailed level for their particular operations, perhaps using the fault trees developed for this project as a basis to ensure that a systematic approach is taken. From an operational perspective, further sub-categorisation of each of the existing six precursors could be useful, with sub-categories agreed at a European level, though not in the form of regulation, as discussed in Section 3.2.13. It is unclear to many RUs/IMs how the reporting of precursors for regulatory purposes contributes to improving safety, and lagging indicators alone may be the only appropriate regulatory indicators at the European level given the lack of contextual data available to ERA, for example.

ERA could consider playing a greater role in the facilitation of the sharing of good practice across European railways, in a way which focusses on continuous improvement of organisational safety culture. This would be likely to result in a natural evolutionary process towards harmonisation, but may be quite a different approach from the regulatory role to which ERA is assigned. The distinction between regulator and operator is an important distinction to maintain, but a facilitator may help to bridge the gap between the two. In the UK, for example, RSSB is able to fulfil such a role, because it is not a regulator or an operator itself.

A facilitating body could usefully build upon the structures proposed within the fault trees produced within this project, to develop more common language, understanding and classification of both accidents and precursors. As was seen in the context of signals passed at danger, for example, there is currently a wide variety of subtly different understandings of what is meant and, therefore, comparisons between the number of SPADs is not entirely meaningful, particularly if used for regulatory purposes. ERA may wish to collaborate with member states and other relevant bodies, to determine how such a facilitating body could be developed, and to ensure that any body established becomes a true asset to all levels of safety monitoring in Europe.

Promoting and developing the common taxonomy in the ERAIL database for the consistent classification of accidents and precursors may best be done by the facilitation of and consultation with appropriate stakeholders, rather than by regulation, and would be useful for a variety of reasons. As has been discussed, the use of 'drop down' lists rather than free text fields will make it more straightforward to identify accident causes using the ERAIL database to gain a better understanding of the frequency of different causation chains. By employing a suitable taxonomy, accident data analysis in the future would better facilitate the identification of precursors that might be gathered by ERA, NSAs and RUs/IMs. The process of improving the consistency of language employed and then better understanding accident causation, is likely to be an on-going iterative process, rather than something which is done once and then fixed, for two reasons. Firstly, because accident causation will be increasingly understood, but secondly because railways themselves will evolve, partly in response to this continually improving understanding – what were important precursors once upon a time will cease to be important precursors as more automation is introduced, for example.

As a common taxonomy is developed, specifically to classify causal factors (e.g. using the terms presented in the fault trees produced for this project), the possibility of using the ERAIL and/or UIC databases to benchmark performance and to identify meaningful trends will become more realistic. To gain maximum value from such a database, making it available online with an appropriate permissions model could be particularly useful. The permissions model, for example, could enable live access to the latest available accident and precursor data, but with details anonymised as appropriate (which may be a particular concern for competing operators, for example). It may also be beneficial for the CSIs to be extended to cover all accidents and incidents investigated by the NIBs, so that the occurrences in one ERAIL dataset are all contained within the CSIs in the other ERAIL dataset (see Section 2.5.3 and Section 4.3).

The use of precursors for operational reasons is vital to the proactive management of safety. Railway stakeholders across Europe are keen to share best practice with each other, and ERA might reasonably make the most of this by continuing to work constructively and appropriately with stakeholders to develop a more harmonised European railway system.

5.7 Summary

The aim of this study was to identify accident precursors that are theoretically sound and reasonably practical to implement at an operational and management level. This study:

1) Identified accident precursors and constructed generic fault trees to display graphically the accident precursors for six key accident types.
2) Gained insight into the accident precursors reported and monitored at NSA, IM and RU level across member states, to understand current practice and the motivations behind it.
3) Identified a harmonised set of accident precursors that might be used for safety management at EU, NSA, RU and IM levels, by combining the theoretical accident precursor fault trees and the actual, practical understanding of accident precursor reporting and monitoring.

It may be informative for NSAs, RUs and IMs to consider precursors identified as being large contributors to risk, and precursors gathered by other NSAs, RUs and IMs. Provisional definitions for high risk precursors are suggested.

The careful selection of CSIs is critical to ensuring that they do not distort performance or detract from other activities that contribute to improving safety. When considering how precursors might be used, a clearer distinction might be required between precursors used for regulatory purposes and precursors used for safety management purposes. To facilitate precursor monitoring and increase its value, there is a need to ensure that there is a good 'safety culture' across the rail industry.

The use of precursors for operational reasons is vital to the proactive management of safety. Railway stakeholders across Europe are keen to share best practice with each other in this field, and ERA should make the most of this by continuing to work constructively and appropriately with stakeholders to develop a more harmonised European railway system.

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Appendix A Literature review search terms

Group 1

- Rail
- Railway
- Train
- Locomotive

Group 2

- Risk model
- Accident classifications
- Precursors
- Accident precursor
- Accident cause
- Causal factors
- Fault tree
- Logic tree
- Contributory factor
- Performance indicator
- Fault path
- Safety reports
- Early warning indicators

Group 3

- Derailment
- Collision of trains
- Collision with obstacle
- Level crossing accident
- Accident to persons caused by rolling stock in motion
- Collision with pedestrian
- Fires in rolling stock

Group 4

- Trespassers
- Platform train interfaces
- Falls from platforms
- Falling out of train
- Struck by train
- Signals passed at danger
- Signal passed at stop
- Obstruction on train line
- Misrouting
- Wrong side signal failure
- Runaway train
- Buffer stop collision
- Infrastructure failure
- Track fault
- Signallers errors
- Rolling stock failures
- Train failure
- Train driver errors

Appendix B Fault trees

The fault trees are presented in a separate PDF file.

Appendix C Tabulated list of step 1 priority precursors

Accident Type	Level 1 precursors	Level 2 precursors	Level 3 precursors	Level 4 precursors
Derailments - passenger train	Derailment due to human error	Signaller error (including wrong route)		
	Derailment due to faults on switches and crossings	Defective switches and crossings		
Derailments - freight train	Derailment due to human error	Signal passed at danger with derailer / trap points		
		Other staff errors		
Collisions of trains	Driver error leading to train train collision	Driver fails to check aspect of signal past control point		
	Runaway train			
Collisions with obstacles	Collision with other objects	Collision with road vehicle on the line as a result of a road traffic accident		
	Collision with items left on the line by vandals			

Accident Type	Level 1 precursors	Level 2 precursors	Level 3 precursors	Level 4 precursors
Level crossing accidents	Road vehicle accidents and incidents – Road vehicle	Road vehicle driver actions causes collision	Deliberate actions of the driver causes collision	Road vehicle driver ignores warning of approaching train
			Accidental (error) actions of the driver causes collision	Road vehicle driver does not observe the crossing & associated warnings
	Pedestrian and cyclist accidents and incidents – Non road vehicle	User error on crossing	Distracted/dragged by dog	
			Fails to stop, look, listen	
		User violation on crossing	Climbs over or under barrier	
			Ignore lights/barrier	
			Cut across in front of train	
Fires in rolling stock	Fires on the outside of trains	Diesel engine fault		
Accidents to persons caused by rolling stock (excluding suicides)	Injury to person on platform	Fall from platform and hit by train	Alcohol or drugs contributes to fall from platform	
			Accidental slip/fall onto tracks	
		Person hit by train whilst still on platform	Struck by a protruding part of train e.g. open door	
	Injury to person lineside	Injury to employee lineside	Unsafe system of work / protection	
	Injury to person on train	Injury resulting from train lurching as a result of braking		

Appendix D RU/IM filter questionnaire for Step 2

Prospective Study into Harmonised Train Accident Precursors Analysis and Management for RUs and IMs

About the study

The European Railway Agency (ERA) has commissioned this study to explore the range of rail accident precursors that are monitored by RUs and IMs across Europe. The purpose is to develop a set of harmonised 'fault trees' so ERA can model the precursors for six important accident types. These accident types are: derailments; collisions with trains; collisions with obstacles; level crossing accidents; fires in rolling stock; and accidents to persons caused by rolling stock (excluding suicides). ERA hopes that this work can be used to develop the range of safety indicators that are reported across Europe.

TRL is conducting the study on behalf of the Agency.

Accident precursors: a definition

We would like to ask you some questions about those indicators that are related to **precursors** of rail accidents. Accident 'precursors' are those incidents and events that might cause a rail accident. Six indicators related to accident precursors are already collected across Europe indicators as part of the Common Safety Indicators (CSIs) framework. They are: broken rails; broken wheels; broken axles; track buckles; SPADs; and wrong-side signalling failures.

You might also refer to an accident 'precursor' as a:

- Causal factor
- Cause
- Contributory factor
- Safety (performance) indicator
- Safety irregularity

Please answer the following questions:

1. Does your organisation **collect** accident precursors?

   Yes ☐ No☐

2. Does your organisation **use** accident precursors in any way?

   Yes ☐ No☐

3. Has your organisation created a safety model that includes accident precursors?

   Yes ☐ No☐

4. Has your organisation developed 'fault trees' (also known as 'causal trees' or 'hazard trees') to link specific precursors with specific accident types, such as derailment?

   Yes ☐ No☐

5. If you answered 'yes' to any of these questions, we may want to contact you.

   Please provide contact details below for a representative who would be willing to have a short discussion with TRL by telephone. Translation services can be made available.

Organisation name	
Type of organisation	Choose an item.
Name of a representative	
Email	
Telephone	
Country	Choose an item.

Please return your completed questionnaire by email to TRL.

Thank you for your time

Appendix E RU/IM topic guide for Step 2

Interview guide for RUs and IMs

About the study

The European Railway Agency (ERA) has commissioned this study to explore the range of rail accident precursors that are monitored by RUs and IMs across Europe. The purpose is to develop a set of harmonised 'fault trees' so the Agency can model the precursors for six important accident types. These accident types are: derailments; collisions with trains; collisions with obstacles; level crossing accidents; fires in rolling stock; and accidents to persons caused by rolling stock (excluding suicides). The Agency hopes that this work can be used to develop the range of safety indicators that are reported across Europe.

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Accident precursors: a definition

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You might also refer to an accident 'precursor' as a:

- Causal factor
- Cause
- Contributory factor
- Safety (performance) indicator
- Safety irregularity

We would like to record the conversation for our records. You will not be personally identified in any data or report that is produced by this study. Is that ok?

☐Yes

☐No

In addition, you can choose whether your organisation is identified in our report as assisting this study or whether you would like your organisation, and any precursor information provided, to remain anonymous?

Organisation to remain anonymous?

☐Yes

☐No

1. Clarify understanding of the term 'accident precursor'

Before we continue with the discussion, we would like to check that you are happy with the definition of an 'accident precursor'.

2. Precursor data collection

We would now like to discuss each of the accident precursors that are collected by your organisation.

Overall, how many different types of precursor does your organisation record?

- Does that number include the six precursors from the set of CSIs? (broken rails; broken wheels; broken axles; track buckles; SPADs; and wrong-side signalling failures)
- *If the total (excluding the CSI indicators) is greater than 10, consider requesting a written response for the remainder of section 2 using the response table provided)*

We would like to discuss the details of each precursor. Beginning with the first precursor, for each precursor please can you provide the:

- **Name** – What is the precursor called?
- **Definition** – What is the definition used for this precursor?
    - o Was this precursor defined by your organisation or is this definition used elsewhere?
    - o Are there any alternative definitions for this precursor? In what circumstances are alternative definitions used?
- **Associated accidents** – What accident type(s) is this indicator a precursor for? (e.g. derailments; collisions with trains; collisions with obstacles; level crossing accidents; fires in rolling stock; and accidents to persons caused by rolling stock (excluding suicides))
- **Purpose** – Why did you start monitoring this precursor?
    - o Please provide details (e.g. in response to an accident/incident; based on expert judgement; in response to industry or European guidance)
    - o Is this precursor used to estimate accident frequency? (e.g. an incident will occur 1 in every 100 times that the precursor is reported). If yes, what are the estimates?
- **Frequency of occurrence** – How often does this precursor occur?
    - o Number of occurrences per reporting period (e.g. monthly, six-monthly, annually, less often)
    - o How is this precursor reported? Do you use a normaliser? (e.g. no of occurrences per 1000 train kms)
- **Frequency of reporting** – How often are data for this precursor reported?
    - o Routinely (if so, please specify the reporting period – e.g. monthly, six-monthly, annually, less often)
    - o On request (in which circumstances? – e.g. in response to particular incidents)

- **Reliability and quality** – How reliable is this precursor? Specifically:
    - o How consistent are the data across the reporting periods? Why do variations occur (if at all)?
    - o How accurate is the monitoring of this precursor? How does the accuracy of reporting change over time?
    - o Is this precursor under-reported? If so, how do you know? What is the estimated level of under-reporting? Why does under-reporting occur? (e.g. different definitions, difficult to identify, poor reporting system)
- Who are these precursor data reported to? (e.g. NSA, other industry members, general public (via website, annual reports, etc), internal use only)

Can you share with us the data you have collected on any or all of these precursors?

In general, why does your organisation gather data on accident precursors?

- What are they used for?
- How are they used? (e.g. analysis, preventative measures, safety performance monitoring, SMS compliance, data collection only)

How do you rank the contribution of a precursor to an accident, such as a derailment?

- Do you decide the probabilities based on expert judgement, data, other?
- Do you organise precursors into fault trees for each accident type?

How do you decide what matters most to your organisation's future safety performance?

3. Improving precursor data collection

Which precursors do you think should be monitored across Europe to deliver the greatest safety benefit?

- In addition to the six indicators that must be reported as a set of CSI accident precursors, what do you think are the top three accident precursors that should be reported in Europe to help improve safety, in order of importance?
    - o How would you define each of these precursors?
    - o Why have you ranked them in this way?
    - o Why do you think it is important to monitor each one? How would/could they be used?
    - o How easy or difficult is it to collect data on each one? What problems might exist with data collection?
    - o If your organisation does not already monitor these precursors, why not?

What are the difficulties associated with monitoring precursors? Consider:

- Difficulties within your organisation
- Difficulties within your Member State
- Difficulties across Europe

How could the monitoring of precursors be improved? Consider:

- Improvements to your own procedures
- Improvements to procedures within your Member State
- Improvements to procedures across Europe

What do you think of the current indicators related to precursors of accidents that are monitored at European level? For each indicator (broken rails; broken wheels; broken axles; track buckles; SPADs; and wrong-side signalling failures), please consider:

- Is it useful to your organisation?
- How easy or difficult is it to collect this information reliably?
- Is the definition set at European level clear?
- Any other comments?

4. Your organisation

☐ An RU

☐ An IM

In which Member State(s) do you operate? In each State, what parts of the network does your organisation cover?

How many staff work in your organisation?

What is the size of your organisation's operations?

- Length of network (IM)
- Number of rolling stock (RU)
- Number of train kms travelled

Appendix F Tabulated list of step 2 priority precursors

Accident type	Level 1 precursors	Level 2 precursors
Derailments	Runaway	
	Axle box overheated or fails	
	Rolling stock faults	Wheel failure
		Braking failure
		Coupling failure
	Human error	Loading error – uneven or insecure (Freight trains only)
		Train overspeeding
	Track faults	
	Environment	
Collision of trains	Human error, lack of attention, misunderstanding, poor communication	Signaller operational error
	Runaway	
	Signalling failure	
	Rolling stock faults	Braking failure
	Violation of rules	
Collisions with obstacles	Human error, lack of attention, misunderstanding, poor communication	
	Signalling failure	
	Braking failure	
	Collision with an out of gauge item on a passing train (loading error)	

Accident type	Level 1 precursors	Level 2 precursors
Level crossing accident	Human error, lack of attention, misunderstanding, poor communication	Train overspeeding
	Failure of the level crossing equipment causes a collision	
Fire in rolling stock	Axle box overheated or fails	
	Fire due to human error / carelessness	
Accident to people caused by rolling stock in motion (excluding suicides)	Incidents with doors on RS	Malfunction or failures in doors of the rolling stock (RS faults)
		Train leaves with doors open (human error, RS faults)
		Caught in doors and dragged (human error, RS faults)