National Institute for Public Health
and the Environment
Ministry of Health, Welfare and Sport

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Technical report on failure frequencies of Dutch freight wagons based on incident data

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RIVM report 620550010/2014

Colophon

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This investigation has been performed by order and for the account of the Ministry of Infrastructure and the Environment (I&M), Directorate-General for the Environment and International Affairs (DGMI), within the framework of project M/620550/10/VG.

Abstract

Towards a new risk-calculation method for the transport of dangerous goods by rail
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Dutch law stipulates that dangerous goods may only be transported by rail following a determination of the risk of fatal accidents. A standard method is applied in the Netherlands to calculate the risk of such accidents occurring. Using this method, it is possible to calculate the size of the area within which fatalities may occur if flammable or toxic substances are released as a result of a train accident. As the current risk-calculation method is based on failure frequency data dating back to the period before 1995, the Dutch National Institute for Public Health and the Environment (RIVM) has updated the relevant information. This update has resulted in a number of points for attention that must be considered in developing a new risk calculation method.

In this study, RIVM has determined the risk of an accident resulting in the release of dangerous gases or liquids from freight wagons. The damage frequencies were based on collision and derailment cases in the Netherlands. Because no accidents resulting in the release of dangerous gases or liquids occurred in the Netherlands during the surveyed period, RIVM factored in accidents occurring in other European countries to calculate the outflow factors following a collision or derailment.

Because in the past no accidents involving the release of gases occurred in the Netherlands, it was assumed at the time that the outflow factor for gases following a collision or derailment was smaller than the outflow factor for liquids. According to this RIVM study, however, the outflow factors for gases and liquids do not differ greatly. Additionally, the available transport data are not sufficiently detailed to take into account several risk factors, such as the train speed or the number of passages at railroad switches.

Keywords:
Railway, railway transport, dangerous materials, dangerous goods, hazardous substances, risk analysis, failure frequency, third-party risk

Rapport in het kort

Op weg naar een nieuwe rekenmethodiek voor het vervoer van gevaarlijke stoffen per spoor
Technisch rapport: faalfrequenties voor Nederlandse goederenwagens op basis van incidenten

In Nederland wordt een vastgestelde methode gebruikt om het risico op een ongeval door het transport van gevaarlijke stoffen over het spoor te bepalen. Hiermee kan de omvang van een gebied worden bepaald waarbinnen mensen kunnen overlijden als ontvlambare en giftige stoffen door een treinongeval vrijkomen. De ‘faalfrequenties’, die in de huidige rekenmethodiek zijn gebaseerd op ongevallen van vóór 1995, zijn door het RIVM geactualiseerd. De actualisatie leidt tot aandachtspunten die in een nieuw te ontwikkelen rekenmethodiek moeten worden meegenomen.

In het onderzoek is specifiek in kaart gebracht wat de kans is op een ongeval waarbij gevaarlijke gassen en vloeistoffen uit goederenwagens vrijkomen. Omdat er in Nederland in de beschouwde periode geen ongevallen hebben plaatsgevonden waarbij deze stoffen zijn vrijgekomen, zijn voor de herziene kansen op botsingen en ontsporingen de Nederlandse ongevalsgegevens aangevuld met Europese ongevallen.

Indertijd is, wegens afwezigheid van Nederlandse ongevallen met gassen, aangenomen dat de kans dat gassen uitstromen na een botsing of ontsporing kleiner is dan bij vloeistoffen. Uit het RIVM-onderzoek blijkt echter dat de uitstroomkansen voor gassen en vloeistoffen weinig van elkaar te verschillen. Ook blijkt dat de beschikbare vervoersgegevens onvoldoende gedetailleerd zijn om rekening te houden met verschillende risicofactoren, zoals de snelheid waarmee gereden wordt of het aantal keren dat een trein een wissel passeert.

Trefwoorden:
spoorvervoer, gevaarlijke stoffen, risicoanalyse, faalfrequentie, externe veiligheid

Contents

Summary

Transport of dangerous materials by rail poses risks to the environment. Serious incidents with an outflow of flammable or toxic materials can be lethal to the public. The government recognises this hazard and wants to protect the public. Fortuitously, serious incidents are very rare, but because of that, it is challenging to properly quantify the risks.

Since safety and dangers around the railway track in the past, present, and future can never be physically measured, models are proposed. In general, models are capable of simulating only parts of the reality. When enough information can be gathered from data, the parameters can be incorporated in the model. However, in some cases, either proven or unsubstantiated assumptions were or must be made. The question remains what to include and what to exclude from a model, keeping in mind the lack of data.

In the Netherlands, calculation methods for the transport of dangerous materials by rail have been introduced in 1995. The methods estimate risks for the open track and shunting yards separately. Until today, the risks are calculated using failure frequencies and visions based on incidents and performance of the Dutch railway system before 1995. However, the system has evolved in the last 20 years, and it will continue to develop with for instance new safety systems and different amounts and types of dangerous-materials transport. An update of the failure frequencies and risk-calculation method is urgently needed. The Ministry of Infrastructure and the Environment (formerly Ministry of Transport) has requested an investigation into the actualisation of the failure frequencies.

The present report proposes a new set of Dutch failure frequencies of derailments and collisions of freight wagons carrying flammable and toxic gases, and flammable liquids. It analyses in detail a more recent set of Dutch incidents with damage to freight wagons in the period 1996-2005. As mentioned above, outflow incidents are very rare, and in fact, they did not occur in the Netherlands in that period. Therefore the relevant leaks from a set of 15 European countries are put forward to obtain European leak frequencies. This set of leaks is only for the processes of whole freight trains, not for shunting operations however.

On the one hand, the Dutch damage frequencies are based on information with a reasonably level of detail, whereas on the other hand, the European leak frequencies are based on case data with considerably less detail. To arrive at Dutch leak frequencies for freight train processes, the two incident sets are coupled via so-called outflow factors. The case data used in this report suggest that the difference between outflow factors for liquids and gases is not as large as what was suggested in 1995. The consequence of this finding is that the transport of gaseous materials has a higher leak frequency than what is currently in use in the Dutch risk-calculation method. In fact, that outflow factor for gases was not based on actual gas leaks, for gas leaks did not occur in the Netherlands up to 1995.

A new set of leak frequencies is only a part of a future risk-calculation method; that is why the report is entitled 'Towards a new risk-calculation method'. We recommend defining a project to develop the method based on the findings and views of this report, and those of reports on for instance the quantitative effect of measures. In the present study, several aspects such as the regular performance as function of train speed, numbers of switches passed, and numbers of shunting operations carried out, could not be satisfactorily addressed. Hopefully, the absent data can be retrieved while constructing the

new risk-calculation method. Recommendations on which other features should be included in the method, such as the scenarios that follow the occurrence of a relevant leak, are listed as well.

The work has been carried out by RIVM in cooperation with an advisory team including Dutch experts knowledgeable on risk calculations for rail transport of dangerous materials. Their constructive and timely comments are appreciated. As a quality check, this report has been peer reviewed by three independent experts.

1 Introduction

Transport of dangerous materials by rail poses risks to the environment. Calculation methods to estimate these risks have been introduced in 1995. The basis of the failure frequencies for the open track and shunting yards are the studies of [SAVE95a,SAVE95b] which are based on incidents in the Dutch railway system that occurred before 1995.

The current failure frequencies and risk-calculation methods are described in two draft reports: [HART11] for the open track (based on earlier work of [SAV95a]), and [SAVE06] for shunting yards (based on earlier work of [SAVE95b]). These frequencies no longer represent the present-day circumstances of rail transport, due to growth of transport, technical and organisational developments, and safety measures. On top of that, the current methods cannot easily accommodate safety measures to reduce the risks for the open track and shunting yards.

The Ministry of Infrastructure and the Environment (formerly Ministry of Transport) wanted to update the failure frequencies by using more recent case reports. This is the main aim of this report. Furthermore, instead of starting with a strict separation of rail segments (open track versus shunting yards) the different processes carried out by the trains are taken as the starting point.

The present report with new frequencies and visions does not yet contain the new risk-calculation method. Throughout this report, the future risk-calculation method is announced, however.

1.1 Failure frequencies

The rate with which an engineered system or component fails is called a failure frequency. For rail transport of freight, the failure frequencies have the unit per arrival, per departure, per other train (or wagon) movement, per train kilometre, per wagon kilometre, per train, or per wagon. Since rail systems evolve, it is recommended to update failure frequencies on a regular basis.

Substantial leaks of dangerous materials of freight wagons have not occurred in the Netherlands during the time period used for the present study. Therefore, in this report we use two endpoints for failure. These are the numerators of the failure frequencies:

- damage to a freight wagon (with or without dangerous materials) using incident cases in the Netherlands;
- leak of a freight wagon (with a relevant outflow of dangerous materials) using incident cases in Europe.

For the numerator we looked at the number of incident cases within a certain time period. The other requirement for a failure frequency is the denominator. This are the performance data of the system during the time period: number of arrivals or departures, other movements, train kilometres, wagon kilometres, numbers of trains or numbers of wagons.

A crucial aspect of this report is that the Dutch damage frequencies of freight wagons are coupled to the European leak frequencies. The rationale is that relevant outflow of dangerous materials has not occurred in the Netherlands within the observation period. Estimating leak frequencies based on zero incidents is not desired. Therefore, the area (observations) for leaks is expanded to Europe. For the European data we are able estimate leak frequencies, but a drawback is that very little information can be retrieved with respect to input parameters such as the process of the train and the speed of the train, which is needed for a risk-calculation method. However, those parameters are included in the Dutch set of damage to general freight wagons. By linking the two sets at the same level of detail, outflow factors can be derived. An outflow factor (a number smaller than one) will tell how many of the Dutch wagons are expected to evolve to a relevant leak. When the Dutch damage frequencies are multiplied by the outflow factors, estimates for the Dutch leak frequencies are assembled. One might fear the Dutch frequencies for damage are based on the inclusion of too many minor incidents which could never have evolved to relevant outflow. However, this is no issue because the outflow factor which is derived from the two sets, automatically corrects for that.

1.2 Overview of the report

This report contains schematic incident trees such as the one presented in Figure 1. They branch out to different types of incidents and damage to freight wagons with several factors such as speed, and finally an outflow factor that translates damage to leak.

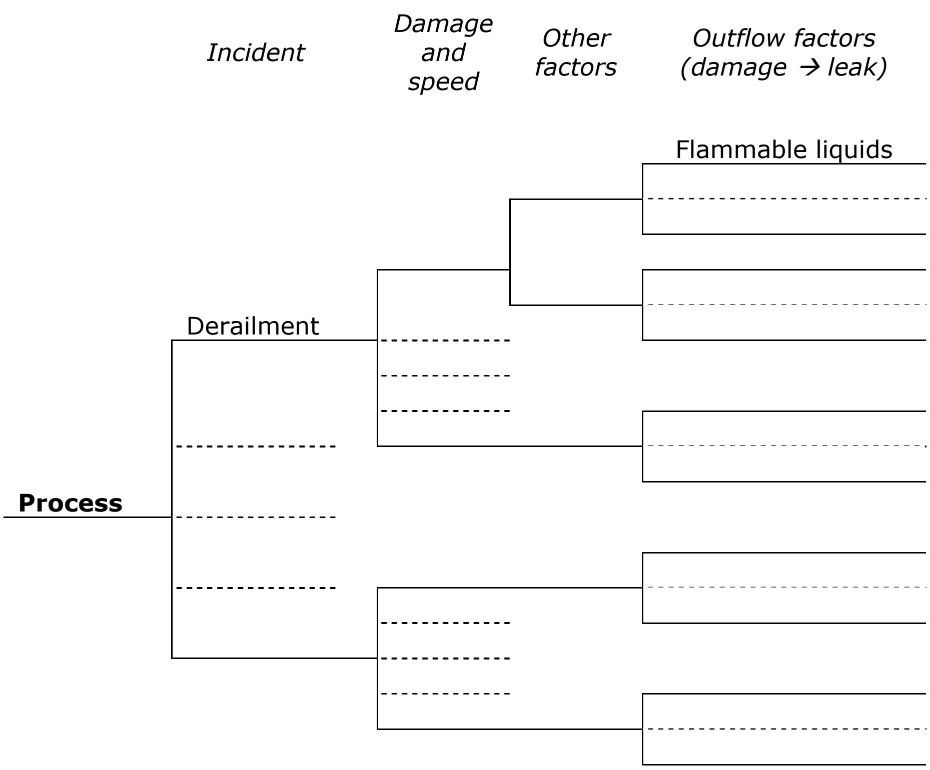

Figure 1 Schematic organisation of a generic incident tree.

The structure of the report is organised according to the ‘rail track map’ (Figure 2). This Section describes per Chapter the contents and the correlations with other Chapters.

Chapter 2: Classification of the incidents
Chapter 2 contains the way the incidents are labelled. The classification used in this report uses the perspective of the process or activity undertaken by the train during the incident. Furthermore, the incident type (e.g. derailment), type of train, speed of the train, presence of railway switches, and the number of wagons involved are taken in consideration.

Chapter 3: Dutch incidents with freight trains
Chapter 3 uses the classification of Chapter 2 to categorise the 229 Dutch incident case reports that were obtained for the period 1996-2005. For each process, an incident tree is constructed, containing the number of incidents per incident type as well as the average number of wagons damage per incident. For transporting freight trains, a further division is made into speed categories of the freight trains during the incidents. An important remark is that Chapter 3 focuses on damage to wagons carrying any type of freight in the Netherlands.

Chapter 4: European incidents of freight trains with relevant leaks
Chapter 4 presents a set of relevant outflow incidents during rail transport of toxic or flammable materials in Europe for the period 1985-2004. Most of these incidents took place outside the Netherlands. To some extent, the set also uses the classification of Chapter 2, but the international case reports are much less detailed than the Dutch set of incidents featured in Chapter 3. Another important contrast between Chapters 3 and 4 is that the latter focuses on freight wagons with significant leaks of toxic or flammable materials in Europe. There is no overlap between the incidents of Chapters 3 and 4.

Chapter 5: Regular performance (denominators)
Chapter 5 gives an overview of the regular performance of the system for the year 2005. The regular performance will provide the denominators. It covers the Dutch amount of train kilometres and an estimate for the number of arrivals and departures as well as the dangerous-materials performance in Europe. At present, the exact numbers of wagons undergoing the processes defined for shunting yards are lacking. The Dutch rail performance data (denominators) of Chapter 5 is linked to the damage events (numerators) of Chapter 3. The traffic performance for dangerous materials in Europe is linked to leak events of Chapter 4.

Chapter 6: Dutch incident and damage frequencies for freight wagons
Chapter 6 combines the Dutch results of Chapter 3 and Chapter 5. The numerators and denominators give damage frequencies (per wagon km). The Dutch damage frequencies are only estimated for freight trains because of the lack of performance data on shunting operations. Speed is a prominent parameter in the incidents (Chapter 3) but it is absent in the performance data (Chapter 5). Therefore, the speed-dependence in the failure frequencies is limited.

Chapter 7: Leak frequencies for international cases
Chapter 7 is similar to Chapter 6 in the sense it combines numerators and denominators, but now for Europe. In this case, the outcome for relevant leaks (Chapter 4) is divided by the performance of dangerous materials (Chapter 5). Leak frequencies are obtained for toxic and flammable gases (RID/ADR Class 2) and flammable liquids (RID/ADR Class 3).

Chapter 8: Outflow factors: from damage to leak
Chapter 8 uses input from Chapter 7 and Chapter 6 to come to outflow factors which tell how many of the wagons damaged are expected to evolve to a relevant leak. This is based on the link between damage of general freight wagons in the Netherlands and leaks of freight wagons carrying dangerous materials in Europe. This link is central in this report. It is assumed the Dutch damage frequencies for derailments and collisions are applicable to all kinds of freight wagons, that is, including those carrying dangerous materials. Chapter 6 holds many details, whereas Chapter 7 is less specific. Therefore, in Chapter 6 an aggregated Dutch set is prepared (combining all processes for freight trains) to compare one-to-one with the European frequencies of Chapter 7.

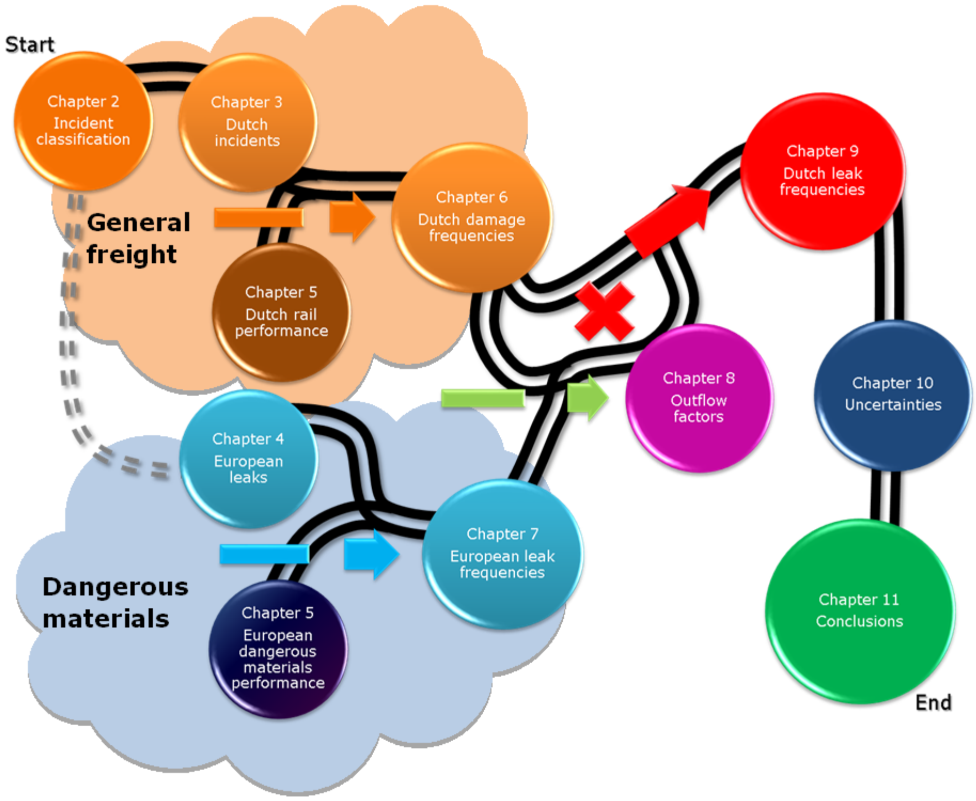

Figure 2 Overview of the report showing the 'rail track map' with the relationship between the chapters. The journey starts at the upper-left corner and ends at the lower-right corner. The dotted track points out that 'Chapter 2' cannot be followed completely to describe 'Chapter 4'. Horizontal lines (vinculums) indicate the division of results of two distinct chapters. The outcome of the arithmetic operation is the next chapter on the track. An example is 'Chapter 3'/'Chapter 5' → 'Chapter 6'. The times sign suggests that results of Chapters 6 and 8 are multiplied to arrive at Chapter 9. The input data stems from two different clouds; one based on general freight and the other on dangerous materials.

Chapter 9: Dutch leak frequencies
Chapter 9 derives the Dutch leak frequencies. These are the products of the Dutch damage frequencies of Chapter 6 and the outflow factors of Chapter 8. Chapter 9 also contains comparisons with the current leak frequencies for transporting trains [HART11]. A first simulation of the current scenarios at shunting yards with the Dutch incidents of 1996-2005 is made, but in the absence of appropriate denominator data, these results are preliminary.

Chapter 10: Uncertainties and validation
Until Chapter 10 single values or so-called point estimations with often three significant figures, are put forward. However, point estimations should be contrasted with confidence interval estimations to have an indication of upper and lower bounds. Chapter 10 lists some uncertainties with respect to the data presented in the previous chapters. One of the highest-ranking topics is the uncertainty in the Dutch denominator data for arriving, departing, and shunting trains. In addition, the European statistics database could not provide all necessary data. Also speed is an important parameter according to the incident reports for both damage and relevant leaks, but the available traffic performance data do not contain denominator information of this aspect. Finally in Chapter 10, the expected number of leaks of dangerous materials is validated for the Netherlands, France, and Germany.

Chapter 11: Conclusions and recommendations
Chapter 11 summarises the conclusions of this report. It also gives recommendations for the development of a new risk-calculation method for the transport of dangerous materials by rail in the Netherlands.

2 Classification of the incidents

This chapter describes the way railway incidents[a] are interpreted and analysed in this report. From a viewpoint of risk analyses, a relatively new classification is put forward here. The main ingredients for the classifications originate from the set-up of the Dutch railway incident database, from discussions with ProRail (responsible for the Dutch railway infrastructure) and from processing the Dutch incident case reports of derailments and collisions of freight wagons.

The freight wagons in the incident case reports transport any kind of material, not only dangerous materials. Furthermore, damage to locomotives, passengers wagons, infrastructure and persons is not part of this research. Logistic problems following a railway incident and financial or legal consequences of incidents are no subject either.

The classification put forward in this chapter is followed in Chapter 3 for the analyses of the Dutch incident reports with freight trains and in Chapter 4 for relevant-leak incidents in Europe. The latter reports are however much less specific.

2.1 Incident types

A loss of containment (LoC) occurs when a hazardous substance is released from the secure packaging. It can arise from two different causes. On the one hand, there are impact incidents where the envelope of the dangerous material fails because of high-energetic forces as a result of a railway incident. On the other hand, circumstances of intrinsic failure of the containment can give rise to LoCs. These are due to causes which are related to the state the containment (such as corrosion) or its incorrect exploitation (such as overfilling). Intrinsic failure is explicitly not addressed in this study, for it is not considered as a consequence of a derailment or collision. This observation does not mean that no attention should be paid to intrinsic failure in the future risk-calculation method.

Table 1 and Figure 3 summarise the high-energy rail incident types used in this study. Within these incidents two categories exist; one-sided (unilateral) and two-sided (bilateral) incidents. A derailment is considered unilateral as long as no interaction with another train preceded the derailment. Two other incident types involve, in principle, merely one train; a buffer-stop interaction and an interaction on a level crossing with a road vehicle which has enough mass to derail the train. The term interaction is used here to indicate the difference from the term collision that is reserved for trains colliding with each other.

Table 1 Descriptions of incident types used in this study.

Incident type	Description
Unilateral incidents	derailment, not caused by another train
	buffer stop interaction
	level-crossing interaction with a road vehicle
Bilateral incidents (collisions)	rear-end collision on a stationary or slower train moving in the similar direction
	lateral collision, a.k.a. side-on or flank collision
	head-on collision, a.k.a. frontal collision

[a] The term ‘incidents’ is used throughout this report. It has a wide range of severity including all derailments, collisions, events, accidents, significant, relevant or serious accidents, calamities, and anomalies with freight wagons. By using the generic term ‘incident’, flagrant or subtle differences between the definitions as proposed by e.g. [ERA12] are no issue here.

Bilateral incidents involve two trains. They include collisions on the same track, either moving in the opposite direction (head-on collision) or moving slower in the same direction or with a stationary vehicle (rear-end collision). In addition, separate tracks can be the location of an incident when two trains laterally interact (lateral collision). A lateral collision takes place where two tracks merge (at a railway switch) or when a train is wider than it should have been (e.g. open doors) and consequently overlaps the other track. When two trains are involved, the incident is always described from the perspective of the freight train or the rake with at least one freight wagon. The other train can be any kind of train (including work trains, single locomotive, or passenger rolling stock).

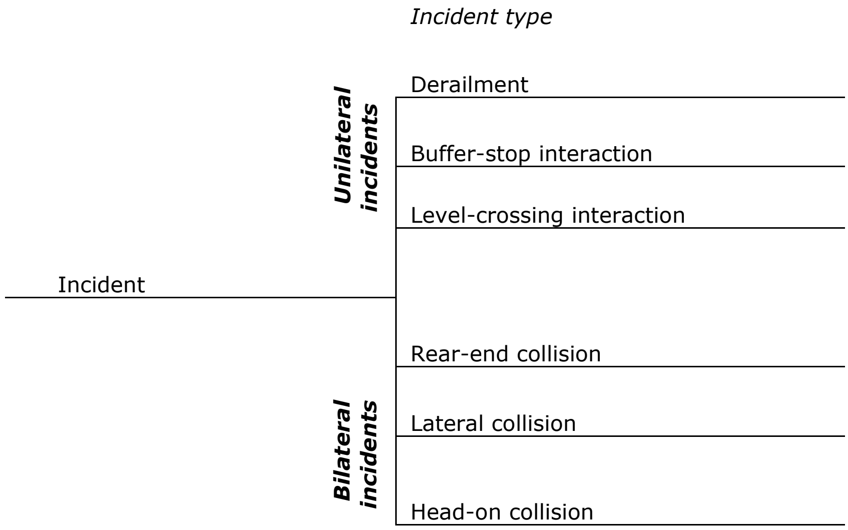

Figure 3 Division of incidents into unilateral and bilateral incident types.

2.2 Characteristics of the location

In the earlier studies by SAVE [SAVE95a,SAVE95b, SAVE06] the railway was divided in distinct rail segments. These segments form the basis for the present-day risk calculation methods; risks for open tracks are calculated with RBMII [HART11], whereas shunting yards are considered as an establishment and are calculated with SAFETI-NL. Instead of such a strict division in rail segments as a starting point, a more process-based division of the rail system is made. The rail segments (Table 2) are however interpreted and available in the case report analysis. The allocation of processes to the present rail segments, legislations or software is not addressed in this report.

Table 2 Rail segments (explicitly not used in this study).

Segment type
Open track
Station w/o shunting
Shunting yard
Private siding

2.3 Characteristics of the infrastructure

The Dutch incident database (analysed in Chapter 3) lists a few parameters, like whether a form of automatic train control was implemented in the track. Also the track speed, the maximum speed which could be driven at the track at the time of the incident under the best of signal aspects, is indicated in the analysis. This can be different from the actual speed driven by the train during the incident (see Section 2.5).

If according to the case report a switch was present in the vicinity of the incident, this is noted too, sometimes as a diverging switch. However, presence is not necessarily the main cause of the incident. Other infrastructural items, such as whether the area has a centrally controlled operation management or not, presence of bridges, tunnels, level crossings, platform tracks, curves and so on, are not included in the set of generic failure frequencies derived in this report. Such items can be put forward, if relevant, at a later stage in the future risk-calculation method to fine-tune the frequencies or to investigate reduction factors following the implementation of measures.

In addition, the density or intensity of freight and passenger trains passing by at certain locations of the rail system ('hot spots') can influence the accidentology. In this report these parameters are absent, since suitable information in both incident reports and the regular situation (the number of times an infrastructural item was passed without irregularities) still needs to be gathered and analysed.

2.4 Characteristics of the rolling stock

2.4.1 Train types

The incidents used in this study involve at least one freight wagon. For this study, there is a difference between complete trains and sections of trains. Table 3 shows the descriptions of train types. We define a freight train that includes at least one locomotive and one freight wagon, and it travels with a train number. Other train types are sections of trains. These are rakes of at least one freight wagon, a single locomotive, rakes of at least one passenger wagon. Furthermore, also passenger trains can play a role in an incident, as long as a freight wagon is involved as well.

A special train type is a work train. It will often carry freight for maintenance, and therefore incidents with work trains were found by the query as well. The materials these trains transports are however used exclusively for maintenance of the rail system. Work trains will never transport dangerous materials and therefore they are not added to the set of freight trains. An incident with a work train will only be used in this study when an interaction occurred with a freight train or a rake of at least one freight wagon.

Special attention is also given to a single locomotive. This label is given to a train that does not transport a wagon of any kind during the incident. An incident with a single locomotive will only be used in this study when an interaction occurred with a freight train or a rake of at least one freight wagon.

Table 3: description of train types used in this study

Train type	Description
freight train	a train consisting of at least one locomotive carrying at least one freight wagon, with or without dangerous materials (travelling with an officially assigned train number)
rake of freight wagons	a certain number of freight wagons (at least one), with or without locomotive (this train type is travelling without an officially assigned train number)
single locomotive	solitary locomotive moving without wagons
work train	train carrying freight exclusively for rail maintenance
passenger train	train consisting of at least one traction vehicle and used for public transport
rake of passenger wagons	a certain number of passenger wagons, with or without locomotive, without passengers

2.4.2 *Processes*

As mentioned above, instead of a division in rail segments, this study takes the different processes into consideration as the basis for new failure frequencies. Shunting is the process of sorting items of rolling stock into complete trains, or the reverse. These operations take place at shunting yards.

The processes are summed up in Table 4 and Figure 4. At a later stage, policy makers can decide on how processes are connected to separate railway segments used in legislation.

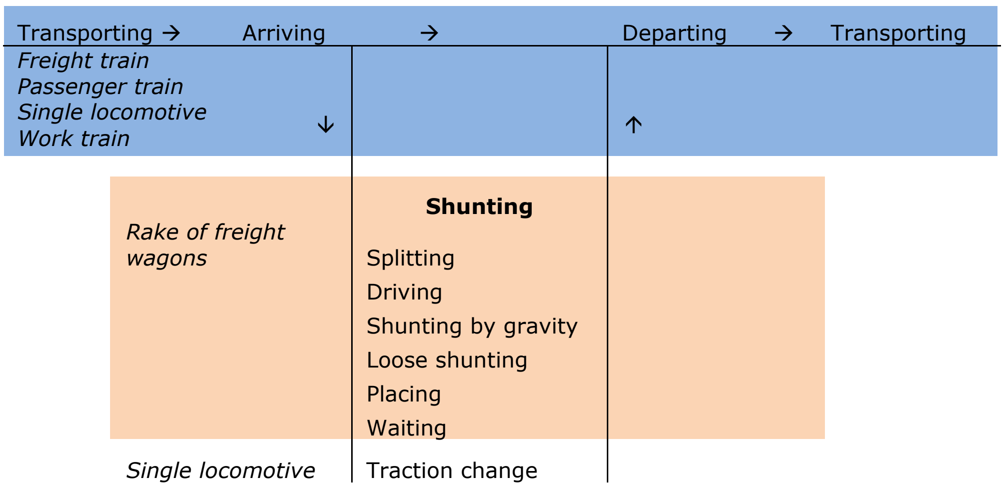

Figure 4 Schematic view of processes for different types of trains. The blue box contains processes that can be carried out by several types of trains. The pink box only shows shunting processes for rakes of freight wagons.

Table 4 Description of process types used in this study.

Process	Description
Transporting	transporting or transferring freight wagons from one place to another; the train is *en route* (carried out by freight trains)
Arriving	arriving at a shunting yard, a station w/o shunting, or a private siding (carried out by freight trains)
Departing	departing from a shunting yard, a station w/o shunting, or a private siding (carried out by freight trains)
Shunting – driving	driving on a shunting yard or a private siding without the direct intention to compose or split trains
Shunting by gravity	composing or sorting trains by rolling freight wagons down a hump or hill by gravity
Loose shunting	pushing uncoupled wagons which continue autonomously after traction of the locomotive stops
Shunting – placing	shunting of freight wagons with the direct intention of placing a rake of wagons at another rake
Shunting – splitting	splitting or pulling sets of freight wagons apart at a shunting yard
Traction change	changing the traction vehicle, either the locomotive or its direction
Waiting	waiting of rakes of freight wagons (note that a freight train with speed 0 km/h is labelled differently)

Not all train types can perform each process. The first three are exclusively for freight trains. Furthermore, although freight trains can stand still for a certain time, this is not regarded as waiting but as transporting, arriving, or departing.

2.5 Train speed

The speed of the train driven at the time of the incident is an important parameter. A higher speed will increase both kinetic energy and impulse of the train in case of an incident. Most of the time, the last registration of the train speed is indicated in the incident case reports. It is not necessarily the track speed, i.e. the maximum speed allowed at a certain track.

The train speed recorded during the derailment is influenced by other factors. The train driver may have observed an irregularity (in rolling stock or track) and consequently lowered the speed before the incident actually took place.

The train speeds during the incidents are clustered in categories: up to 20, 21-40, 41-60, 61-80, and 80+ km/h. Another approach gives two broader categories: low speed (LS) for speeds during the incidents ≤ 40 km/h, and high speed (HS) for speeds during the incident > 40 km/h. These two speed categories LS and HS are in use in [HART11] as well, and will be put forward in this report also.

2.6 Causes

It is not always possible to indicate the cause or, more specifically, the direct single cause of an incident. If the cause is known, one could argue whether a certain measure would be effective in preventing or mitigating similar incidents in the future. It is questionable whether all incidents which originate from deviations from the standard operations procedures or from not obeying regulations or conventions can be precluded by measures. Actions outside the normal prescribed routines include speeding, ignoring signals, sub-standard maintenance, and inadequate training of drivers and other personnel. The present study will not elaborate on whether incidents are recognised as the consequence of illicit behaviour, design flaws, external conditions and so on.

2.7 Damage to rolling stock

For the Dutch dataset (Chapter 3) we focus on freight wagons with any kind of material. A main ingredient, but not the easiest to quantify, is the damage to rolling stock. The severity of damage to freight wagons has to be interpreted from very different descriptions in the incident reports, which makes this a delicate task. It turned out the definition of 'wagon damaged' varies with the situation and the purpose of the investigation. For the Dutch set, a conservative definition is chosen: wagons damaged in any way are registered.

Some incidents encompass the collision of two freight trains. In that case, the total number of freight wagons damaged for both trains will be taken. The generic tree for each process of Table 4 is shown in Figure 5.

	Incident type	*Number of incidents*	*Wagons damaged*	*Average damage (wagons/incident)*
Process / *Train type*	Derailment	n_1	d_1	a_1
	Buffer-stop interaction	n_2	d_2	a_2
	Level-crossing interaction	n_3	d_3	a_3
	Rear-end collision	n_4	d_4	a_4
	Lateral collision	n_5	d_5	a_5
	Head-on collision	n_6	d_6	a_6

Figure 5 Generic schematic view of counts of incidents (n_i), absolute number of wagons damaged (d_i), and average number of wagons damaged (a_i) per incident type.

The international set (Chapter 4) does not show the number wagons damaged but the number of leaking wagons, because only incidents with severe outflow of flammable or toxic materials are included. The damage in that case is defined as the number of wagons with a loss of containment of quantities of dangerous materials having the potential for causing fatalities through flame contact, heat radiation or inhalation of toxic vapours or gases. These possible fatalities do not include railway personnel, but only people in the surroundings that are not associated with the activity of transporting dangerous materials.

2.8 Summary and next steps

This Chapter gives the overview of how the incidents in the following chapters are labelled and interpreted. The focus is on the relatively detailed Dutch set of 229 incidents with freight wagons transporting any kind of material. We continue with this Dutch set in Chapter 3. Thereafter follows Chapter 4 with 34 European incidents which gave rise to relevant losses of containment of flammable and toxic (by inhalation) materials. Eventually, in Chapter 8, these two will be linked.

3 Dutch incidents with freight trains

This Chapter contains the results of the interpretation and categorisation of the Dutch incidents. The outcome of this examination will be used as numerators for the incident and damage frequencies. Annex 1 contains a brief overview of the classifications of the incidents. The incident case reports themselves are not included in this report.

The Dutch Railway Inspectorate used the database with the Dutch acronym called MISOS (Management Information System for Irregularities Railway Safety) to categorise incidents up to 2005. The main reason to identify incidents for the Inspectorate is to take (cost-) effective counteractions to prevent future anomalies. This is different from the aim of the present study, where the incidents are used for the derivation of failure frequencies of freight wagons. The MISOS database is set up with a number of fields, partly comparable to the classification of Chapter 2 and includes links to various documents. From 2006 onward a new database called HAZARDS is in use[b].

The Inspectorate provided RIVM with the results of a query to obtain a list of all derailments and collisions from MISOS in the period 1996-2005, including the underlying incident reports. Analyses on the MISOS set were done earlier by the Dutch Railway Inspectorate itself, but a re-interpretation of all cases was carried out to extract more information on processes and train speed. On top of that, the present set contains 229 incidents instead of the earlier selection of 171 cases. As an indication of repeatability, according to the two analyses, for the overlapping 171 incidents the number of freight wagons was in agreement for 86% of the cases.

3.1 Incidents

From MISOS we took all incidents with freight wagons. Passenger trains will only be part of this report if they interacted in bilateral incidents with freight trains. In total 229 incidents form the basis for the Dutch numerators. The interpretation of the 229 incidents from the query is shown in Annex 1. Please note that only the fields relevant in this analysis are included there.

Table 5 shows how the 229 incidents in MISOS are assigned to incident types. Most obvious is the large share of derailments in this set.

[b] A quick scan of MISOS (1996-2005) and HAZARDS (2006-2010) indicated that on average the amount and type of incidents as well as location indicators were fairly similar for the two sets. It was agreed to leave out the HAZARDS database in the present analyses because (1) the quick scan shows the same ´primary´ accidentology, (2) the HAZARDS database has a different set-up and combining two sets will introduce uncertainties, and (3) the interpretation of about 110 extra case reports would be time consuming. However, it is necessary to use HAZARDS in future updates of failure frequencies or risk-calculation methods for Dutch freight wagons.

Table 5 Number of train types per incident type (Dutch dataset MISOS, 10 years).

Incident type	Freight train	Rake of freight wagons	Work train	Single locomotive	*Sum*
Derailment	35	104	8	1	*148*
Buffer-stop interaction	1	18		1	*20*
Level-crossing interaction	1	2			*3*
Rear-end collision	6	31	1		*38*
Lateral collision	12	4		1	*17*
Head-on collision	2	1			*3*
Total	**57**	**160**	**9**	**3**	***229***

The 229 incidents are not equally distributed over the years (Figure 6). Within the MISOS set, a difference between the years 1995-1999 and 2000-2005 is observed. It is indeterminate whether this truly reflects that from 2000 onwards the Dutch railway became less safe. Changing criteria of the Inspectorate for incident documentation might play a role here. Various other reasons are suggested, e.g. an increase in performance or traffic (hence incidents), changing priorities in reporting (diligence), organisational changes, and incomplete registration of events at private sidings and shunting yards.

It must be kept in mind that the relatively low number of incidents in the years 1996-1999 is followed by a relatively high number of incidents in the period 2000 to about 2005 (second half MISOS). One might even suggest splitting the dataset to be used for the derivation failure frequencies. Nevertheless, statistical tests for the significance of possible inconsistencies in the set are only possible if the performance (of both traffic and the organisation registering the incidents) is known for all years. Without hard evidence of inaccuracies in registration, we continue with the entire set for 1996-2005.

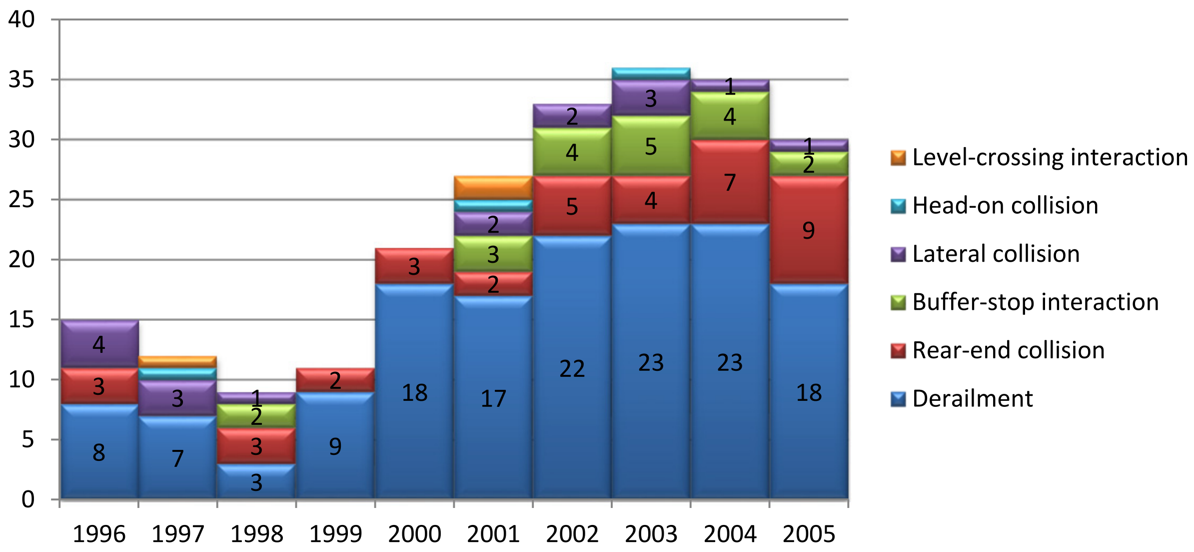

Figure 6 Number of incidents involving freight wagons in the period 1996-2005 by incident type and year (Dutch dataset MISOS, 10 years).

The type of the train and the process at the moment of the incident are indicated in Table 6. When compared to Table 5, Table 6 provides an additional level of detail. The summed data in the right-hand column of Table 6 are identical. The following remarks are made:

- Almost half (104/229) of the incident reports are on a rake of freight wagons that underwent a derailment.
- 39% (90/229) of the incidents occurred during the process ´Shunting – driving´.
- Incidents during ´Shunting – splitting´ have not been observed in the MISOS cases studied.
- Incidents labelled ´Shunting – traction change´ are apparently absent in Table 6. However, they did take place: 3 of the 19 rear-end collisions of the rakes of freight wagons occurred when a waiting rake was hit by a single locomotive.

Table 6 Number of incident types and processes per train type (Dutch dataset MISOS, 10 years).

Type train	Incident type	Transporting	Arriving	Departing	Sh. driving	Sh. placing	Sh. by gravity	Loose shunting	Waiting	*Grand Total*
Freight train	derailment	20	5	10						*35*
	buffer-stop interaction			1						*1*
	level-crossing interaction	1								*1*
	rear-end collision	3	2	1						*6*
	lateral collision	7	1	4						*12*
	head-on collision	2								*2*
	sub-total	*33*	*8*	*16*						*57*
Rake of freight wagons	derailment				75	20	5	4		*104*
	buffer-stop interaction				2	15			1	*18*
	level-crossing interaction				2					*2*
	rear-end collision				4	3	5		19	*31*
	lateral collision				2	1			1	*4*
	head-on collision					1				*1*
	sub-total				*85*	*40*	*10*	*4*	*21*	*160*
Work train	derailment	4	1		3					*8*
	rear-end collision								1	*1*
	sub-total	*4*	*1*		*3*				*1*	*9*
Single locomotive	derailment				1					*1*
	buffer-stop interaction				1					*1*
	lateral collision			1						*1*
	sub-total			*1*	*2*					*3*
Grand total		**37**	**9**	**17**	**90**	**40**	**10**	**4**	**22**	***229***

So far, we looked at the incidents, or entries, in the database. The following Section focuses on the number of freight wagons damaged during these incidents. In the next Section we look at the freight trains.

3.2 Number of wagons damaged: freight trains

Table 6 shows there were 57 incidents involving a freight train. During these incidents a total of 132 wagons were damaged. Figure 7 shows how these 57 incidents and 132 wagons are distributed per process and per incident type.

Freight train		*Incident type*	*Number of incidents*	*Number of wagons damaged*	*Average damage (wagons/ incident)*
Departing	16	Derailment	10	17	1.70
		Buffer-stop interaction	1	0	0.00
		Rear-end collision	1	4	4.00
		Lateral collision	4	9	2.25
Transporting	33	Derailment	20	67	3.35
		Level-crossing interaction	1	1	1.00
		Rear-end collision	3	1	0.33
		Lateral collision	7	17	2.43
		Head-on collision	2	0	0.00
Arriving	8	Derailment	5	12	2.40
		Rear-end collision	2	1	0.50
		Lateral collision	1	3	3.00
		total	*57*	*132*	*2.32*

Figure 7 Incident trees with number of incidents and average number of wagons damaged per freight train process and incident type (Dutch dataset MISOS, 10 years). Branches with zero incidents are left out.

Because the interaction of a freight train with a buffer stop happened only once in 10 years and no freight wagon got damaged, this branch is left out of the further analysis. Also only one interaction at a level crossing took place, resulting in one wagon damaged in 10 years. For the time being, this incident is left out of further analyses[c]. Instead of the 57 incidents of Figure 7, we continue the analysis with 55 incidents, either derailments or collisions between two trains.

[c] For the derivation of a failure frequency at level crossings, we need the total number of passages at level crossings in the 10-year period as a denominator. It is difficult to obtain such a number. In [HART11] the level-crossing surtax has been left out. The future risk-calculation method should investigate this topic.

Compared to the derailment branches, the branches for the three types of collisions are relatively empty. To simplify the incident tree we propose to aggregate these collisions in this report. Figure 8 shows the new tree that contains only branches for derailments and collisions. Please keep in mind that at a later stage in a future risk-calculation method the collisions branch must be split to three different branches for rear-end, lateral, and head-on collisions. We are aware that these incident types are not exactly comparable[d] and for the implementation of measures to prevent or mitigate rail incidents the separate branches are necessary. For the moment we accentuate that lateral collisions are most prominent within collisions of the Dutch MISOS set.

Freight train		*Incident type*	*Number of incidents*	*Number of wagons damaged*	*Average damage (wagons/ incident)*
Departing	15	Derailment	10	17	1.70
		Collision	5	13	2.60
Transporting	32	Derailment	20	67	3.35
		Collision	12	18	1.50
Arriving	8	Derailment	5	12	2.40
		Collision	3	4	1.33
		total	*55*	*131*	*2.38*

Figure 8 Simplified incident trees with number of incidents and average number of wagons damaged per freight train process (Dutch dataset MISOS, 10 years).

The following Sections take the separate branches, either derailment or collision, of Figure 8. We first look at derailments and investigate the speed parameter of the freight trains.

3.2.1 Speed influence: derailments

First we focus on derailments only, for derailments have no external influence from other trains. Speeds indicated in the incident case reports and used in this report are the speeds driven at the time of the incident. As can be seen in Figure 8, there are 10 derailments for departing, 20 for transporting, and 5 for arriving freight trains.
Figure 9 indicates the speed categories for these derailment branches. When there are too many branches, the incident density per branch gets too low. This will be a weak basis for a model. For the moment we suggest to aggregate the five speed categories of 20 km/h to two broader categories:

- Low speed (LS): speed during the incident ≤ 40 km/h;
- High speed (HS): speed during the incident > 40 km/h

Incidents labelled ‘departing’ only arose at low speeds in MISOS: 10 incidents with 17 wagons damaged (average 1.70 wagons per incident). The incidents during the process ‘arriving’ also took place at low speeds only: 5 incidents with 12 wagons damaged (average 2.40 per incident).

[d] Be informed that the prevailing method is less specific: all incidents (derailments and collisions) are put together.

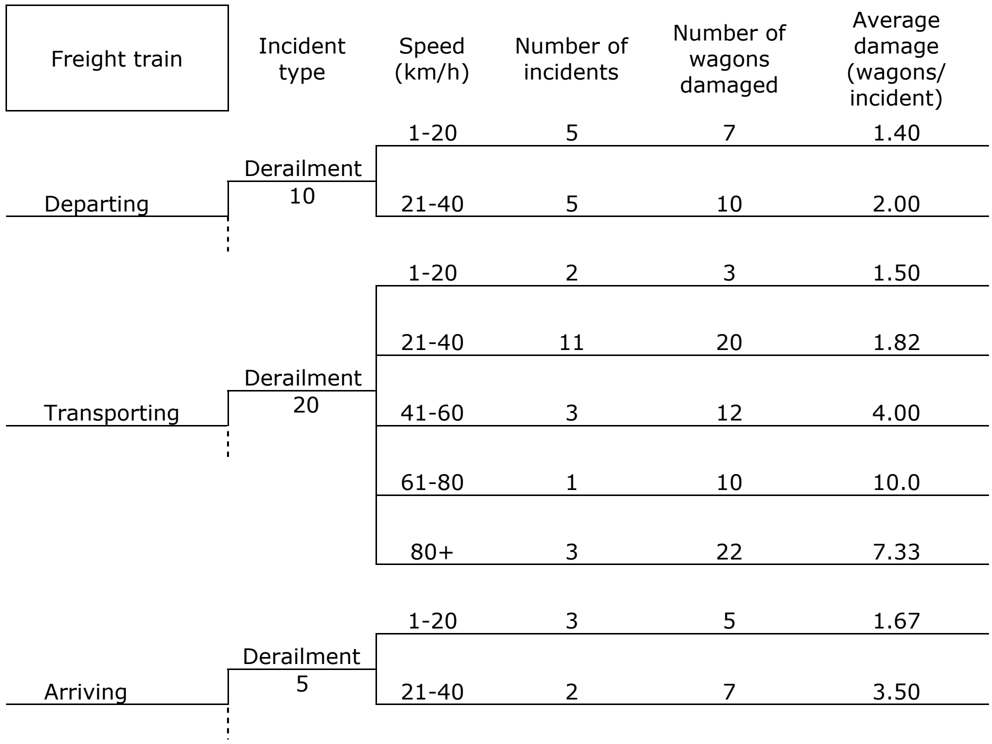

Figure 9 Incident tree with the branches for derailments of freight trains with a division in speed categories (Dutch dataset, 10 years). Branches for collisions are left out (indicated by dotted lines).

Table 7 gives the results for the process 'transporting'. It suggests that about two times more incidents occur at low speeds than at high speeds (13 versus 7). However, the number of wagons damaged is over three times higher at HS compared to LS (6.29 versus 1.77).

Table 7 Number of derailments, wagons damaged and average per speed category for transporting freight trains (Dutch dataset MISOS, 10 years)

Speed (km/h)	**Number of derailments**	**Number of wagons damaged**	**Average (wagons damaged per derailment)**
1-20	2	3	1.50
21-40	11	20	1.82
sub-total LS	*13*	*23*	*1.77*
41-60	3	12	4.00
61-80	1	10	10.00
80+	3	22	7.33
sub-total HS	*7*	*44*	*6.29*
Total	**20**	**67**	**3.35**

The following step is to combine all 35 derailments during all processes (transporting, arriving, and departing) for the freight trains. The results are shown in Table 8. Because incidents labelled 'arriving' and 'departing' happened at low speeds, the results for high speeds do not change.

Table 8 Number of derailments, wagons derailed and average per speed category for arriving, transporting, and departing freight trains (Dutch dataset MISOS, 10 years).

Speed (km/h)	Number of derailments	Number of wagons damaged	Average (wagons damaged per derailment)
1-20	10	15	1.50
21-40	18	37	2.06
sub-total LS	28	52	1.86
41-60	3	12	4.00
61-80	1	10	10.00
80+	3	22	7.33
sub-total HS	7	44	6.29
Total	**35**	**96**	**2.74**

The main remark on Table 8 is that especially for speeds higher than 40 km/h too few data are available. In the category 61-80 km/h only one incident is registered. Therefore, we turn to the larger so-called DNV-ERA set of derailments registered in Europe instead of in the Netherlands only. DNV has collected derailment incidents of freight trains from a large number of European countries in the context of an ERA project [DNV11]. It is emphasised that only (initial) derailments during the process of transportation by freight trains are included. RIVM obtained the data sheet with 201 derailment cases from the authors of the DNV report. The results of our analysis on this European set are described in Annex 2.

The speed of the trains during the incidents is also present for 137 out of the 210 derailments. This parameter is not used to the same extent by [DNV11] as in this study. In our study, further analyses on the cases are made, with the intention of verifying, appending, and collecting the speed driven during the derailment and the number of derailed wagons.

One can argue whether 'damage' in derailments in MISOS and 'derailed' in DNV-ERA can be compared. Here, the main results are shown for the derailments with speed indications. The more detailed results are shown in Annex 2.
Table 40 of Annex 2 is used in this Section as Table 9.

Table 9 distributes the set of 137 European derailments into the speed categories. This number is much higher than the Dutch amount of derailments. MISOS only includes seven derailments of freight trains in the higher speed categories above 40 km/h (Table 8), while DNV-ERA contains 58 derailments which makes the relation between speed and average derailed or damaged wagons more substantiated. Note that instead of the 10-year period for MISOS, a longer period of 16-years is used in the DNV-ERA study. As for the Dutch dataset, the average number of wagons derailed is larger for high speeds than for low speeds. For this set it is a factor of about two (6.16 versus 2.90).

The average number of wagons derailed per speed category is normalised to the total average of 4.28 wagons per incident. The last column of Table 9 contains the normalised averages.

Table 9 Number of derailments, wagons derailed, and average per speed category for European derailments; the last column contains the relative factors (see Annex 2, European dataset DNV-ERA, spanning 16 years).

Speed (km/h)	Number of derailments	Number of wagons derailed	Average	Normalised average
1-20	27	64	2.37	0.55
21-40	52	165	3.17	0.74
sub-total LS	*79*	*229*	*2.90*	*0.68*
41-60	17	89	5.24	1.22
61-80	21	135	6.43	1.50
80+	20	133	6.65	1.55
sub-total HS	*58*	*357*	*6.16*	*1.44*
Total	**137**	**586**	**4.28**	**1.00**

The Dutch absolute average for HS in Table 7 (6.29) corresponds to the European average for HS in Table 9 (6.16). This suggests the high-speed derailments more or less match. This is not applicable for the LS derailments, which are further apart: 1.77 (Table 7) or 1.86 (Table 8) for the Netherlands versus 2.90 (Table 9) for Europe. We put forward this is probably the consequence of the inclusion of relatively less significant LS incidents in the Dutch set, whereas the DNV-ERA set embraces only the relatively more substantial LS incidents. In Chapter 6 the damage frequencies for derailing freight trains will be expressed with a speed correction factor. Instead of the set of 20 Dutch derailments, we propose to use the European set of 137 derailments to derive speed correction factors of LS (0.68) and HS (1.44) for the Dutch damage frequencies.

It is noteworthy the relative numbers of 0.68 and 1.44 for LS respectively HS (Table 9) are comparable to the speed corrections factors of 0.62 and 1.26 which are presently in use in the Netherlands [SAVE95a,HART11]. Assuming that ‘derailed’ also means ‘damaged’, we propose to use the relative factors (normalised averages) of Table 9 for the Dutch derailments because they are based on more incidents.

3.2.2 Speed influence: collisions

The other half of the tree of Figure 7 deals with collisions and is shown in Figure 10. The maximum number of incidents per branch is three. Only four collisions took place at speeds higher than 40 km/h. In other words, there are too few data to determine the speed influence. The speeds indicated here are the speeds of (one of) the freight trains that carry out the indicated process. If two trains are involved, the damage is now the sum of the freight wagons of both trains. Note that the lowest speed category also contains 0 km/h to include rear-end collisions on waiting freight trains.

Freight train	*Collision type*	*Speed (km/h)*	*Number of incidents*	*Number of wagons damaged*	*Average damage (wagons/ incident)*
Departing 5	Rear-end	21-40	1	4	4.00
	Lateral	1-20	1	2	2.00
		21-40	3	7	2.33
Transporting 12	Rear-end	0-20	2	1	0.50
		21-40	1	0	0.00
	Lateral	21-40	3	10	3.33
		41-60	1	0	0.00
		61-80	2	6	3.00
		80+	1	1	1.00
	Head-on	1-20	1	0	0.00
		21-40	1	0	0.00
Arriving 3	Rear-end	0-20	2	1	0.50
	Lateral	21-40	1	3	3.00
	Collision	total	20	35	1.75

Figure 10: Incident tree with the branches of collisions of freight trains with speed (Dutch dataset MISOS, 10 years). Branches for derailments are left out (dotted lines).

The collisions during transporting are shown in Table 10. It suggests the corrections for low speed and high speed are 0.92 and 1.17. These correction factors are lower than those for derailments. However, the dataset is limited. Nevertheless, we propose to use in this report the relative speed factors of Table 10 (LS=0.92 and HS=1.17) for the collisions.

Table 10 Number of collisions, wagons damaged, and average per speed category for transporting freight trains (Dutch dataset MISOS, 10 years).

Speed (km/h)	Number of collisions	Number of wagons damaged	Average	Relative
0-20	3	1	0.33	
21-40	5	10	2.00	
sub-total LS	8	11	1.38	0.92
41-60	1	0	0.00	
61-80	2	6	3.00	
80+	1	1	1.00	
sub-total HS	4	7	1.75	1.17
Total	**12**	**18**	**1.50**	**1.00**

Table 11 shows the results in case all processes for freight trains are put together. The data suggest there is no difference between low and high speeds, or at least, the incident data does not show it.

Table 11 Number of collisions, wagons damaged, and average per speed category for transporting, departing and arriving freight trains (Dutch dataset MISOS, 10 years).

Speed (km/h)	Number of collisions	Number of wagons damaged	Average	Relative
0-20	6	4	0.67	
21-40	10	24	2.40	
sub-total LS	16	28	1.75	1.00
41-60	1	0	0.00	
61-80	2	6	3.00	
80+	1	1	1.00	
sub-total HS	4	7	1.75	1.00
Total	**20**	**35**	**1.75**	**1.00**

3.2.3 Switch influence

This Section indicates the influence of switches in the incidents. In the current method [HART11], switches play a prominent role. The speed-independent additional damage frequency for a 1-km track which contains at least one switch is 1.2 (HS) or 2.4 (LS) times higher than the initial base damage frequency. In other words, a high-speed track with a switch has a factor 2.2 times higher damage frequency than a high-speed track without switches. For a low-speed track this factor is 3.4.

When examining the MISOS dataset, it turned out the speed is an essential parameter in the collection of derailments in relation to switches. Table 12 shows for derailments the presence of a switch and the number of derailments and wagons damaged. Seven of 13 LS derailments have some kind of connection with a switch, or occurred in the proximity of a switch. It does not automatically mean the switches were the main cause of these derailments. For one of the 13 LS derailments a switch was absent, and for five of the 13 LS derailments the presence of a switch was not clear from the reports. Consequently, for low-speed derailments at least some influence of switches is expected. On the other hand, for the seven HS derailments apparently six had nothing to do with switches. This would suggest that the switch influence on HS derailments is smaller than on LS derailments, or that switches are less common in HS zones. In consequence, adding a speed-independent constant switch surtax [HART11] is not what the cases in this report suggest.

Table 12 Presence of a switch in derailments of transporting freight trains per speed category (Dutch dataset MISOS, 10 years).

Speed category	Switch present?	Number of derailments	Number of wagons damaged	Average
LS	yes	7	12	1.71
	?	5	8	1.60
	no	1	3	3.00
sub-total LS		13	23	1.77
HS	yes	1	10	10.0
	no	6	34	5.67
sub-total HS		7	44	6.29
Total		**20**	**67**	**3.35**

Table 13 shows the presence of a switch in the collision incidents. Like for the derailments of Table 12 for LS, one could put forward that some influence of switches is present for collisions, but for both LS and HS this is less evident. Compared to derailments, switches seem to play a different role in collisions. An important note is that the MISOS reports suggested collisions at or near switches are often the result of an earlier mistake: one of the trains passed a stop signal without authority to do so. In these cases, the presence of a switch is merely one of the conditions for a collision between trains instead of the main cause.

Table 13 Presence of a switch in collisions of transporting freight trains per speed category (Dutch dataset MISOS, 10 years).

Speed category	Switch present?	Number of collisions	Number of wagons damaged	Average
LS	yes	2	4	2.00
	?	4	6	1.50
	no	2	1	0.50
sub-total LS		8	11	1.38
HS	yes	1	0	0.00
	no	3	7	2.33
sub-total HS		4	7	1.75
Total		**12**	**18**	**1.50**

Please take note that the three HS incidents of Table 13 without a switch influence are lateral collisions. This can be explained by the fact that, for some reason, one of the trains was wider than anticipated.

For departing and arriving the speed categories LS and HS were not observed in the incident cases. Table 14 and Table 15 suggest that for derailments more than half of the departing trains and all the arriving trains had some connection with a switch. This is as expected considering the way rail tracks are built at locations where trains arrive and depart: shunting yards and railway stations.

This report do not demonstrate a causal relation between switches and incidents. However, it gives the impression the proximity of a switch is a relevant parameter for incident frequencies. It has to be investigated if the presence of switch can be quantified within the failure frequencies.

Table 14 Presence of a switch in incidents of departing freight trains per incident type (Dutch dataset MISOS, 10 years).

Incident type	Switch present?	Number of incidents	Number of wagons damaged	Average
Derailment	yes	6	12	2.00
	?	1	1	1.00
	no	3	4	1.33
sub-total derailment		10	17	1.70
Collision	yes	3	8	2.67
	?	1	4	4.00
	no	1	1	1.00
sub-total collision		5	13	2.60
Total		**15**	**30**	**2.00**

Table 15 Presence of a switch in incidents of arriving freight trains per incident type (Dutch dataset MISOS, 10 years).

Incident type	Switch present?	Number of incidents	Number of wagons damaged	Average
Derailment	yes	5	12	2.40
Collision	yes	1	3	3.00
	?	1	1	1.00
	no	1	0	0.00
sub-total collision		3	4	1.33
Total		**8**	**16**	**2.00**

3.3 Number of wagons damaged: rakes of freight wagons

In this Section, the incident data for rakes of freight wagons are investigated. Figure 11 indicates derailments are most prominent. Especially derailments during driving and placing are numerous, with average numbers of 1.44 to 1.75 wagons damaged. In addition, buffer-stop interactions during placing (15 incidents) do occur relatively often, but the average damage is relatively low with 0.87 wagons damaged. It is obvious that waiting rakes of freight wagons are hit by other trains, so these are mainly labelled as rear-end collisions on a stationary train (19/21). Of these 19 rear-end collisions, three were considered to be the result of traction change of the other train in the incident, in these cases a single locomotive.

The two last shunting processes of Figure 11 need to be commented. The process of 'shunting by gravity' nowadays occurs only at the shunting yard named 'Kijfhoek'. This process has been thoroughly revised after 2005, so the incidents included in this report may no longer be applicable to the present and future situation. Also 'loose shunting' no longer occurs in the Netherlands and can therefore be discarded in a future risk-calculation method.

Rake of freight wagons	*Incident type*	*Number of inci-dents*	*Number of wagons dam-aged*	*Average damage (wagons/ incident)*
Shunting driving 85	Derailment	75	108	1.44
	Buffer-stop interaction	2	3	1.50
	Level-crossing interaction	2	1	0.50
	Rear-end collision	4	11	2.75
	Lateral collision	2	13	6.50
Shunting placing 40	Derailment	20	35	1.75
	Buffer-stop interaction	15	13	0.87
	Rear-end collision	3	2	0.67
	Lateral collision	1	2	2.00
	Head-on collision	1	3	3.00
Waiting 21	Buffer-stop interaction	1	1	1.00
	Rear-end collision	19	23	1.21
	Lateral collision	1	1	1.00
Shunting by gravity 10	Derailment	5	7	1.40
	Rear-end collision	5	8	1.60
Loose shunting 4	Derailment	4	3	0.75

Figure 11 Incident trees for rakes of freight wagons (Dutch dataset MISOS, 10 years). Branches with zero incidents are left out.

Finally, because suitable denominator data for the shunting incidents are absent (as will be shown in Section 5.4), we did not want to put considerable effort in analysing shunting processes in the present report. In any case, the numerator data of the incidents for the years 1996-2005 are available for further research at a later stage[e,f].

[e] Rough indications of amounts of freight wagons at shunting yards will be used to compare with the prevailing failure frequencies at shunting yards (see Section 9.2.2).
[f] The presence of switches was checked for the shunting processes as well. A first indication show that more than half of the derailments during driving are positively linked with the presence of a switch. Recall shunting yards contain many switches.

3.4 Summary and next steps

The Dutch incidents with freight wagons of the MISOS databases are presented in this Chapter. These incidents are the numerators for the Dutch failure frequencies. For freight trains data are present to divide the processes into two incident types (derailment and collision). Variation in the number of wagons damaged as function of speed categories is suggested as well. The European DNV-ERA set contains much more derailments and is therefore used to estimate average numbers of wagons damaged per speed category. For derailments during the process of transporting, a factor of two is expected between low speed and high speed. For collisions, a smaller variation in expected damage as function of speed categories showed up.

Incidents reports on low-speed derailments often showed the presence or proximity of switches, whereas high-speed derailments on most occasions were apparently not connected to a switch. However, collisions at or near a switch are frequently the consequence of passing a stop signal without the authority to do so.

The shunting operations which gave rise to damage to freight wagons are only briefly discussed in this Chapter. Most of the incidents were derailments of rakes of freight wagons while driving. Because proper denominator data are not available (as will be shown in Section 5.4) and frequencies for shunting operations will not be derived at this moment, it is not worthwhile to further explore these incidents in the present report.

The next steps are first to describe the European relevant incidents for transporting, arriving or departing freight trains with loss of containment (Chapter 4). This is different from the viewpoint of the present Chapter which takes all kinds of damage (often relatively small) to all kinds of freight wagons. Thereafter we will try to find matching denominators for the Dutch and European incidents (Chapter 5). Chapter 6 continues with the ratios of the Dutch numerators and denominators.

4 European incidents of freight trains with relevant leaks

This Chapter contains an analysis of incidents with freight trains which occurred in Europe within the timeframe of 1985 to 2004 (Annex 3) during transporting, arriving or departing. All incidents have a loss of containment (LoC); to be more precise, a relevant outflow of flammable or toxic materials in amounts having the possibility to pose lethal injuries to civilians. In most cases, the exact amount of such a potentially lethal amount of liquids or gases which are flammable or toxic by inhalation is however not mentioned in the reports.

It is assumed the 20-year set of European incidents in this Chapter can be used as a hypothetical representation for relevant leaks in the Netherlands. Apart from this spatial equalisation, this report does not investigate differences between night and day, weather types and seasonal variations.

The materials are grouped in the following ADR/RID classes derived from the United Nations-based system of identifying dangerous materials.

- Class 2 – gases, with the following sub-classes:
  - Class 2.1 – flammable gases
  - Class 2.3 – toxic gases
- Class 3 – flammable liquids
- Class 6.1 – toxic substances (liquids)

This means asphyxiant gases which are non-flammable and non-toxic (Class 2.2), are excluded from this set of incidents. In addition, explosives (Class 1), flammable solids (Class 4), oxidising agents and organic peroxides (Class 5), infectious substances (Class 6.2), radioactive materials (Class 7), and corrosives (Class 8) are not included in this report.

The sources of the dataset are the incident case reports gathered by RIVM in 2009. These include FACTS (*Failure and Accidents Technical information System*), GUNDI (*Gefahrgut-Unfall-Datenbank im Internet*), ARIA (*Analyse, Recherche et Information sur les Accidents*), open literature research, and information of a working group of the RID[g]. To this end, the incidents were re-examined.

The processes of shunting of freight trains are not included in the set of incidents presented in this study, since a decent estimate of the number of shunting operations, which is needed for the derivation of failure frequencies for shunting, is not available. Therefore only incidents with freight trains are considered. From the frequently cryptic or ambiguous descriptions it was not always possible to precisely state the process undertaken by the train. Arriving, departing, and transporting are not always distinguished. Therefore, all processes for the European set of relevant leaks had to be merged.

After removing cases related to shunting and intrinsic failure, double entries, and incidents after 2004 or before 1985, a number of 34 relevant incidents remain. Please note that incidents not connected to flammable or inhalation-toxic properties, such as corrosives (Class 8) and asphyxiant gases (Class 2.2), are excluded. A short overview of the interpretation of the incidents is given in Annex 3. Some of the incidents are without satisfactory background documentation and originate from the partly confidential set of a RID working group. Table 16 gives an overview of this European set. The majority of the

[g] Arbeitsgruppe des Fachausschusses für das RID, 'Standardisierte Risikoanalyses', October 2004.

incidents are connected to Class-3 materials: 25 of them concern flammable liquids. The number of incidents as well as the average number of leaking wagons per incident for Class 3 is higher than for Class 2 (gases) and Class 6.1 (toxic liquids) (Table 17). This would suggest there is more transport of Class-3 materials and Class-3 tanks are more easily damaged to the extent of leaking. Please keep in mind the European set is small and especially Class 2 and Class 6.1 do not include many incident case reports.

Table 16 Overview of the European set of number of incidents with relevant, potentially lethal leaks per country and number of relevant leaks between brackets (20 years).

Country	Class 2	Class 3	Class 6.1	Total
Belgium	1 (1)	1 (1)		2
Denmark		1 (1)		1
Germany	2 (6)	13 (33)	1 (1)	16
France	2 (2)	5 (17)		7
Netherlands		1 (2)		1
Finland		1 (7)		1
Norway	1 (2)			1
Sweden		1 (3)		1
Switzerland		2 (11)	2 (2)	4
Total	**6 (11)**	**25 (75)**	**3 (3)**	**34**

Another remark on Table 17: the average number of relevant leaks in Class-3 incidents suggests there is a difference between collisions and derailments. The Class-2 and Class-6.1 incidents do not suggest a difference between these incident types.

Table 17 Overview of the European set of incidents with relevant leaks (20 years).

Class	Incident type	Number of incidents	Number of relevant leaks	Average relevant leaks per incident
2	Derailment	5	9	1.80
	Collision	1	2	2.00
		6	*11*	*1.83*
3	Derailment	14	54	3.86
	Collision	11	21	1.91
		25	*75*	*3.00*
6.1	Derailment	2	2	1.00
	Collision	1	1	1.00
		3	*3*	*1.00*
Total		**34**	**89**	**2.62**

4.1 Class 2: gases

For this study and present-day quantitative risk calculations, only incidents with flammable gas (Class 2.1) and toxic gas (Class 2.3) are relevant. A large discharge of asphyxiant gas (Class 2.2) may suffocate people close to the scene, but such scenarios are not included in third-party risk analyses for rail activities so far.

Within Class 2 a significant dissimilarity exists for the thickness of tank walls depending on the design pressure for the material in the tank. These are defined by RID regulations. For our study 'thin' gas wagons with wall thickness up to 10 mm (more or less arbitrarily chosen) will transport for instance *n*-butane and vinyl chloride. 'Thick' gas wagons withstand higher pressure of the contents. A main example for this group is liquefied petroleum gas. Out of the six incidents, probably only one is associated with a thick wall. With the present incidents dataset of gas wagons it is therefore not possible to discriminate between the strength of thick and thin walls with different parameters in the leak frequencies.

Concerning the speed categories of the Class-2 incidents, it is pointed out that 4 out of 6 incidents are without speed indications. Therefore, a speed dependency for Class-2 incidents cannot be identified.

4.2 Class 3: flammable liquids

Table 18 shows the speed of the train for the 25 incidents. In more than half of the incidents the speed was not stated in the case reports. Although there are not many cases present in the set, still an increase with speed is observed. The same goes for the broader speed categories 'low speed (LS)' and 'high speed (HS)'. These differ by about a factor 2.

Table 18 European set of derailments and collisions giving rise to relevant leaks of flammable liquids Class 3 per speed category (20 years).

Speed (km/h)	Number of incidents	Number of relevant leaks	Average number of relevant leaks
0	2	2	1.0
1-20	-		
21-40	4	15	3.8
sub-total LS	6	17	2.8
41-60	-		
61-80	3	12	4.0
80+	2	18	9.0
sub-total HS	5	30	6.0
unknown	14	28	2.0
Total	**25**	**75**	**3.0**

The number of 11 incidents with speed indications is not high enough to support splitting up into the two incident types 'derailment' and 'collision'.

4.3 Class 6.1: toxic substances

Class 6.1 embraces toxic substances (liquids) which are liable to cause death or serious injury to human health if inhaled, swallowed or absorbed by the skin. For third-party risk one merely studies risks of acute toxicity via the exposure route of inhalation of vapours. The liquids or vapours which were set free in the three incidents labelled Class 6.1 (see Table 16) are chloroform[h] and epichlorohydrin.

4.4 French rail incidents with dangerous materials

At a later stage during the research a French set of 2,700 rail events (anomalies with freight trains and rakes of wagons) with all types of dangerous materials was provided by UIC/SNCF. Ten of these records showed a breach in a tank wagon. DNV will thoroughly examine the French set of rail events. However, at some points in this report it will be shown that assumptions from other datasets do not contradict the (preliminary) analysis of the French data.

4.5 Summary and next steps

This Chapter describes a relatively small set of relevant European incidents with freight trains transporting Class-2, Class-3, and Class-6.1 materials. To be included, the outflow must have had the potential of causing harm to third

[h] Chloroform is not (yet) classified as acutely toxic by inhalation (according to CLP regulation EC 1272/2008), however.

parties. The case reports do not always show enough detail with respect to process and speed. The most promising European incidents concern the flammable liquids, Class 3. Within this Class, an increase of average numbers of leaking wagons with increasing train speed is detected. The numerator data of this Chapter together with the denominator data (a certain number of wagon km) of Section 5.5 will be used in Chapter 7 to derive the international leak frequencies.

5 Regular performance (denominators)

The counts of incident cases of Chapters 3 and 4 are the numerators of failure frequencies. The denominators are measures of the total population, for instance a distance covered or a number of operations carried out during the observation period.

Estimates of the regular performance are sometimes difficult to obtain, but it is vital that quantities for the denominators are obtained. Without denominators, one is unable to derive frequencies. It is emphasised the numbers put forward in this Chapter are in our opinion at this moment the best available data for the period studied. It is to be expected that when a more recent period will be taken as the base for failure frequencies, the denominators will become more detailed and more robust.

Performance data for rail traffic, both distances and fraction of dangerous materials per Class, were obtained from a public database. The European Commission maintains a website called Eurostat to enhance public access to information concerning the European Union. The goal of the Commission is to keep the data up-to-date and accurate. However, the disclaimer mentions that the information is:

- of a general nature only and is not intended to address the specific circumstances of any particular individual or entity;
- not necessarily comprehensive, complete, accurate or up to date;
- without legal status.

Moreover, Eurostat stresses the information is not suitable to be used professionally. But we anticipate that the quality of the data is sufficient for use in the derivation of failure frequencies.

Most figures put forward in this Chapter and this report show three significant figures. In fact, the numbers are not that precise and need indications of uncertainties (see suggestions in Section 10.1).

5.1 Traffic performance of freight trains in the Netherlands

The resource for traffic performance was found at Eurostat[i]. For most countries, the first entry in the Eurostat database is for the year 2004. We assume the data do not include train kilometres of empty wagons (an incident of an empty wagon will not produce a relevant outflow of dangerous materials either) and that the data express real distances travelled instead of ‘planned’ distances.

According to Eurostat, in the Netherlands a total of 9.26 million freight train kilometres (train km) is found in 2004, and 11.24 million train km in 2005 (see also Table 20). Data before 2004, which cover the MISOS period, are lacking. We use the number of 2005 for all years within the period 1996-2005 in the absence of other data.

[i] See http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=rail_tf_trainmv&lang=en or use a search engine with the keyword ‘rail_tf_trainmv’. Choose the tab ‘Select Data’ and pick from ‘TRAIN’ the label ‘Goods train (TRN_GD)’. Data used in this report are extracted April 18th, 2011.

Premise A
The traffic performance of freight trains in the Netherlands is 1.12×10^8 per 10 year.

Section 3.2 stresses the prominence of the speed driven by the train at the time of the incident. If possible, the denominator (traffic performance in train km) contains this information. However, the traffic performance does not show subdivisions for speed categories. A proxy for the speed driven could be the track speed (maximum speed at a railway track). Although track speeds are known in the Netherlands, it appears not to be an easy task to allocate the performance on the different tracks, according to ProRail. Even if these numbers could be produced, there will still be a difference between speed driven by the train at the time of the incident and track speed.

5.1.1 *Number of wagons in a train*

Another aspect to be considered is the number of wagons transported by a train. For certain viewpoints it is better to consider wagons instead of trains when it comes to failure frequencies. A disadvantage of using wagons instead of trains is that for a train involved in an incident, the wagons carried in that specific train have a much higher chance of derailing or colliding than any random wagon at any moment or place within the observation time and area. This suggests that taking a viewpoint of wagons is precarious.

On the other hand, the disadvantage of using trains instead of wagons is that the numbers of wagons with dangerous materials transported serve as input in the risk calculation. If the assembly of freight trains with dangerous materials were always exactly the same, then the analysis in terms of trains is recommended. However, in general the transport of dangerous material is not constant.

[SAVE95a] found in their incident set an average number of 26 wagons per train, but they proposed the number of 20 freight wagons transported by freight trains instead. The present analysis of MISOS incident case reports with general freight trains involves 58 freight trains and 1542 freight wagons, which gives an average value of 26.6 wagons (Table 19). Rakes of freight wagons carry on average 11.5 wagons according to the incident reports.

Table 19 Average number of freight wagons in trains involved in the incident (Dutch dataset MISOS, 10 years).

Train type	Average number of freight wagons
Freight train	26.6
Rake of freight wagons	11.5

Premise B
The average number of freight wagons in a freight train is 26.6.

Premise C
The average number of freight wagons in a rake of freight wagons is 11.5.

The international incidents of Chapter 4 include 26 freight trains with specified numbers of wagons transported. These trains carried in total 688 freight wagons, giving rise to an average of 26.5 wagons per freight train. In absence of other specific data on the average number of wagons per freight train per country, we propose to use the average number of 26.6 freight wagons (Premise B) throughout Europe.

One could argue these average numbers, based on incidents instead of regular performance, are biased towards a higher number because longer trains are less easy to handle, and consequently more liable to undergo incidents. This is difficult to address. There appears to be no better source which contains the length of freight trains circulating in the period 1996-2005.

5.2 Switches

Section 3.2.3 suggests switches do influence the occurrence of incidents, although a causal relation was not demonstrated. For a correct derivation of the influence of switches on the Dutch failure frequencies, one needs information on the amount of passages in the period 1996-2005 or for instance in 2005. Apart from these amounts, preferably the different types and builds of switches, and in what position they were during the passages, is identified. The requested numbers for this period are not known. A switch surtax within the damage frequencies can therefore not be quantified due to lack of data.

5.3 Arrivals and departures in the Netherlands

Detailed data on the processes of arriving and departing are not available for the period 1996-2005. For future derivations it is recommended to register the denominator information in a more precise way. However, a few sources indicate how many freight wagons have arrived and departed. One data set for the year 2005 was created by ProRail (see Annex 4). Per shunting yard (allegedly the most important 68 shunting yards) it gives the number of freight trains that pull in to be shunted (42,450) and pull out after shunting (42,808). The less than 1% difference between these numbers could be either a miscount or in reality more trains departed than arrived. We propose to use the average for the Dutch shunting yards of 42 629. In light of the lack of data for the other years it is suggested to use this number for all years within the period 1996-2005.

Premise D
The average number of freight trains arriving before shunting and departing after shunting is 426 thousand per 10 years.

Apart from arrivals and departures—before and after shunting, there is an indication of the number of trains passing by. We assume these trains underwent the processes of arriving (entering the rail yard) and departing as well, but did not perform any shunting operation. Annex 4 sums up to 739 796 freight trains passing these 68 yards as a freight train[j]. The total amount of arriving and departing trains is presumed to be 782,425 trains per year.

Premise E
The average number of freight trains undertaking the process of arriving and departing is 7.82 million trains per 10 years.

5.4 Performance at Dutch shunting yards

Preferably, the performance at all Dutch shunting yards contains the following information (per year or per period of 10 years):

- total number of freight trains and freight wagons that attend shunting yards;
- for each of the shunting processes the amount of freight wagons involved;
- for the process 'shunting – driving' an extra indication of either distance covered (wagon kilometres) on the shunting yard or duration of activity (wagon hours);

[j] It remains unclear what the exact context of the numbers of passing trains is. It could also be a combination of arrival and departure including shunting. This may suggest doublings. Therefore this number should be considered as a preliminary indication.

- for the process 'shunting – changing traction' the amount of actions, the number of wagons involved and whether it concerned a change of locomotive or merely a directional change;
- for the process 'waiting' an indication of the duration (wagon hours);
- additional information on freight wagons in general versus freight wagons containing dangerous materials, subdivided in different classes (e.g. Class 2) and sub-classes (e.g. Class 2.1);
- indications of speed driven by the trains.

The data mentioned above are not available for the period 1996-2005. For future derivations it is recommended to register or estimate the denominator information for shunting yards in a more precise way. As a very rough estimate we will use the number of 426 thousand trains that arrived/departed times 26.6 wagons per train, equals 11.3 million wagons in 10 years (Premises B×D).

5.5 Traffic performance of dangerous materials in Europe

The relevant leaks of dangerous materials (DM) need a denominator as well. Eurostat also provides data on the share of DM transport by rail[k]. No information on speed driven or track speed is given in the Eurostat database.

The dangerous materials on the website are divided into ADR/RID Classes, but not all materials have the potential of causing fatalities in the surroundings amongst civilians. For this study only Class 2 'Gases' and Class 3 'Flammable liquids' are applicable. Class 6.1 'Toxic substances' contains fluids which are toxic by inhalation. However, also other routes of exposure (ingestion and absorption through skin) are present within this Class. It is impossible to distinguish between these exposure routes within the traffic performance gathered by Eurostat. Therefore, no suitable Class 6.1 denominator can be derived.

The performance of dangerous materials is given by Eurostat in units of mass, and it is not directly expressed in the unit of train km. Therefore a conversion is done by correcting by the amount of total freight transported in units of tonne kilometres. This is found by the Eurostat information 'rail_go_grgood7'. When the freight for a certain RID Class in tonne km is divided by the total freight, one gets a share per country per Class as will be shown in the next subsections. This share is used to estimate the amount of wagon km. However, it is questioned whether the shares based on mass are the most appropriate factor to get to a performance in the unit wagon km. However, other information is not available. Moreover, the performance value per class is not expressed in the unit train km, because this would infer that each and every train is fully assembled with wagons with either Class-2 or Class-3 materials.

The performance in this Section is given for a set of countries. The question arises how many European countries should be included. There are nine countries which had relevant outflow incidents within the period 1985-2004 (Chapter 4). The selection of 15 countries put forward in this Chapter is based on countries which were part of the European Union in 1995 (EU-15), but also Switzerland and Norway are added (these countries also experienced relevant outflow incidents). The United Kingdom and Ireland are excluded because of their deviating rail system.

[k] See http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=rail_tf_trainmv&lang=en or use a search engine with the keyword 'rail_go_dnggood'. Data used in this report are extracted on April 18th, 2011.

5.5.1 *Class 2: gases*

Table 20 gives the European Class-2 performance, originally in the units train km and tonne km, for the year 2005. The deduced performance for Class 2 in the unit wagon km is estimated at 341 million wagon km. The necessary subsidiary risk classes are not published by Eurostat, so one cannot assess what part concerns the necessary subsets flammable (Class 2.1) and toxic (Class 2.3) gases, and what part of the gases is non-flammable and non-toxic (Class 2.2). ProRail was not able to provide such data either. In one way or another, the performance of 341 million wagon km has to be corrected by the relevant share.

A French set of 1022 Class-2 incidents or anomalies for 2000-2010, provided by SNCF/UIC, contains over 600 cases with asphyxiant gases (according to the Hazard Identification Number (HIN) or GEVI codes 20 and 22). Practically all of these entries did not concern severe incidents with impact on the safety, but the set can be used as an indication on how much of the different sub-classes is transported. Although one cannot be certain the incident registrations are a reflection of the total performance in France, it gives an estimate that 60% of the denominator is not connected to flammable or toxic gases. For this dataset, flammable gases form 22% of the incident registrations and toxic gases 18%.

Another source for an estimate of the relevant share within Class 2 is given by [ERA09]. This study postulates that 40% of the Class-2 traffic falls in the flammable gases category. An estimate of toxic gases is not given, but it might be at least 18% as for the French incidents, summing up to possibly around 60% relevant share as a rough indication. Nevertheless, we postulate that 50% of the Class-2 performance is connected to Class-2.2 gases which are not used in third-party risk calculations; the other half of the performance is considered relevant (flammable and toxic) gases. The last remark on Class 2 that has to be made is that this transport uses various types of tank wall thickness; a distinction which cannot be made within the data from Eurostat.

Table 20 Traffic performance of freight trains in a selection of European countries for the year 2005 (source: Eurostat) and the deduced performance of the share of Class-2 materials based on mass.

Country	**Performance**	**Total freight**	**Class 2**	**Share**	**Performance Class 2**
	(x 10^3 train km)	**(x 10^6 tonne km)**		**(%)**	**(x 10^6 wagon km)**
Austria	49 160	17 062	126	0.7	9.65
Belgium	15 501*	8 130	220	2.7	11.15
Denmark	4 185	1 967	21	1.1	1.19
Finland	16 819	9 706	276	2.8	12.72
France	108 420	40 701	977	2.4	69.19
Germany	190 205	95 420	1 818	1.9	96.35
Greece	1 836	613	130	21.2	10.35
Italy	60 710	20 130	712	3.5	57.09
Luxembourg	1 765	392	1	0.3	0.12
Netherlands	11 239	5 025	162	3.2	9.63
Norway	7 899	3 055	289	9.5	19.87
Portugal	7 674	2 422	0	0.0	0.00
Spain	37 697	11 071	177	1.6	16.02
Sweden	43 865	21 675	321	1.5	17.27
Switzerland**	31 077	11 483	143	1.2	10.29
Total					**341*** **

* Data for 2006
** Data for 2008
*** Using 26.6 wagons per train; of this amount 50% is considered relevant (toxic or flammable)

5.5.2 *Class 3: flammable liquids*

Derived in a similar way, Table 21 gives the European Class-3 performance for the year 2005. The performance is estimated at 967 million wagon km.

Table 21 Traffic performance of freight trains in a selection of European countries for the year 2005 (source: Eurostat) and the deduced performance of the share of Class-3 materials based on mass.

Country	Performance	Total freight	Class 3	Share	Performance Class 3
	(x 10^3 train km)	(x 10^6 tonne km)		(%)	(x 10^6 wagon km)
Austria	49 160	17 062	985	5.8	75.45
Belgium	15 501*	8 130	1 093	13.4	55.40
Denmark	4 185	1 967	17	0.9	0.96
Finland	16 819	9 706	678	7.0	31.24
France	108 420	40 701	2 260	5.6	160.05
Germany	190 205	95 420	9 044	9.5	479.29
Greece	1 836	613	91	14.8	7.25
Italy	60 710	20 130	344	1.7	27.58
Luxembourg	1 765	392	21	5.4	2.51
Netherlands	11 239	5 025	208	4.1	12.37
Norway	7 899	3 055	33	1.1	2.27
Portugal	7 674	2 422	16	0.7	1.35
Spain	37 697	11 071	115	1.0	10.41
Sweden	43 865	21 675	197	0.9	10.61
Switzerland**	31 077	11 483	1 252	10.9	90.08
Total					**967*****

* Data for 2006
** Data for 2008
*** Using 26.6 wagons per train

5.6 Summary and next steps

This Chapter describes the available denominator data. The performance during the regular situation shows the following:

- An average of 26.6 wagons per freight train is derived from the case incident reports. It is assumed these incidents reflect the regular situation in the Netherlands.
- The totals of train kilometres for the Netherlands (all types of freight) are reasonably well registered.
- The totals of train kilometres for 15 European countries (only dangerous materials Class 2 and 3) are reasonably well registered.
- Within Class 2 a significant share concern gases which are not considered toxic by inhalation or flammable: we presume 50% of the 341 million wagon km is relevant, the other half is assumed irrelevant
- For the numbers of freight trains which undertake the processes of arriving and departing the data get less accurate.
- The performance (amount of wagons or handling) during the shunting processes is not known. A very rough estimate is 11.3 million wagons in the Netherlands in 10 year.
- No subdivisions in the performance for the different speed categories are present in the denominator data.

Together with these denominator data we use the incident counts of Chapters 3 and 4 (the numerators) to derive frequencies in Chapters 6 and 7.

6 Dutch incident and damage frequencies for freight wagons

This Chapter will describe the way the failure frequencies for the Netherlands are derived. There are three types of failure frequencies in this report. The first is the incident frequency which estimates how many incidents will take place (if an incident takes place this means that somehow the system failed). The second is the damage frequency which estimates how many wagons will be damaged (after the incident occurs, freight wagons can get damaged to some extent; this is considered a failure too). The third is the leak frequency (not only an incident occurs, but also wagons get damaged and moreover they leak a potentially lethal amount of dangerous materials). The first type does not take into account the damage per incident, whereas the second type contains all wagons independently, so it does not take into account that as soon one freight train undergoes a derailment or collision the chances of damage for the individual wagons are coupled.

The present Chapter shows the first two types of failure frequencies for the Netherlands. Chapters 7 and 9 show leak frequencies for Europe respectively the Netherlands.

6.1 Transporting freight trains

6.1.1 Derailments

Failure frequencies for derailments from the perspective of a freight train are described first. Derailments are the major part of the incidents. In the set of MISOS, a total of 20 freight trains derailed during the process of transporting (Table 6). The incident frequency is 20 derailments per 1.12×10^{8} train km (Premise A) or 1.78×10^{-7} derailments per train km. Assuming a freight train contains on average 26.6 wagons (Premise B) and on average 3.35 wagons are damaged in derailments during transporting (Table 7) one can calculate the failure frequency of 2.24×10^{-8} wagons damaged in derailments per wagon km. Note this number can also be derived by dividing the total number of wagons damaged by the number of train km times the average of 26.6 wagons per train.

> For derailments of transporting freight trains the incident frequency is determined at 1.78×10^{-7} incidents per train km and the damage frequency at 2.24×10^{-8} wagons damaged per wagon km.

6.1.1.1 Speed corrections

The incident cases show that on increasing speed, the average number of damaged wagons increases (Section 3.2.1). This is seen both in the speed categories for the MISOS set (Table 7) and the DNV-ERA set (Table 9). Therefore, the question arises if the damage frequency can be corrected by a speed factor.

The normalised correction factors of Table 9 can only be used if the traffic performance (wagon km) has a similar subdivision over the different speed categories. The subdivision is not known, however. At the moment even a surrogate subdivision based on track speed instead of speed driven, is absent. It still remains a matter of debate if there is an appropriate way to deal with speed.

For the time being we propose to take for derailments the damage frequency of 2.24×10^{-8} wagons damaged per wagon km and to correct this by the relative speed correction factors of Table 9. Table 22 shows the resulting frequencies for wagon damage. The current damage frequencies for LS versus HS in [HART11] resemble these frequencies.

Table 22 Damage frequencies Dutch freight train derailments during transporting with speed correction per speed category using the relative factors of DNV-ERA (see Table 9).

Speed (km/h)	Relative speed correction	Corrected damage frequency (wagons damaged per wagon km)
1-20	0.55	1.24×10^{-8}
21-40	0.74	1.66×10^{-8}
sub-total LS	*0.68*	*1.52×10^{-8}*
41-60	1.22	2.74×10^{-8}
61-80	1.50	3.37×10^{-8}
80+	1.55	3.49×10^{-8}
sub-total HS	*1.44*	*3.23×10^{-8}*
Total set	**1.00**	**2.24×10^{-8}**

6.1.2 *Collisions*

In the set of MISOS a total of 12 freight trains collided with another train during the process of transporting. The incident frequency for collisions is 12 (bilateral) collisions per 1.12×10^{8} train km (Premise A) or 1.07×10^{-7} collisions per train km. Assuming a freight train contains on average 26.6 wagons (Premise B) and on average 1.50 wagons are damaged in collisions during transporting (Table 10) one can calculate the failure frequency of 6.02×10^{-9} wagons damaged in collisions per wagon km.

For (bilateral) collisions of transporting freight trains, the incident frequency is determined at 1.07×10^{-7} incidents per train km and the damage frequency at 6.02×10^{-9} wagons damaged per wagon km.

Table 10 indicates a possibility to introduce speed correction factors on the level of low speed (LS) versus high speed (HS). As for derailments, the use of the speed correction factors for damage frequencies is possibly inappropriate.

Table 23 Damage frequencies Dutch freight train collisions during transporting with speed correction per speed category using the relative speed correction of DNV-ERA.

Speed (km/h)	Relative speed correction	Corrected damage frequency (wagons damaged per wagon km)
LS	0.92	5.52×10^{-9}
HS	1.17	7.03×10^{-9}
Total set	**1.00**	**6.02×10^{-9}**

6.1.3 *Switches*

As discussed in Section 5.2, there are no denominator data for switches to match the numerator data. Therefore, influence of switches cannot be quantified.

6.2 Departing freight trains

Table 24 summarises that in total 15 incidents are connected to freight trains departing from a shunting yard, a private siding or a railway station (see also Figure 8). Speeds found for departing in the MISOS incident set were all below 40 km/h. Consequently, discrimination in LS and HS is absent.

Table 24 Incidents and wagons damaged for departing freight train (Dutch dataset MISOS, 10 years).

Incident	Number of incidents	Wagons damaged	Average damage per incident
Derailment	10	17	1.70
Collision	5	13	2.60
Total set	**15**	**30**	**2.00**

Damage frequencies of departing freight trains should be defined by the number of trains which undertook the process of departing. Therefore, to obtain the damage frequencies we use Premise E, that is 7.82 million trains in the observation period of 10 year. As described in Section 5.3, the uncertainty in the denominator is relatively high. The incident and damage frequencies of Table 25 are therefore first indications.

Table 25 Incident and damage frequencies for departing (Dutch dataset MISOS, 10 years).

Process	Incident frequency (per departure)	Average number of wagons damaged per incident per 26.6 wagons	Damage frequency (wagons per departing wagon)
Derailment	1.28×10^{-6}	1.70	8.17×10^{-8}
Collision	6.39×10^{-7}	2.60	6.25×10^{-8}
Total set	$\mathbf{1.92 \times 10^{-6}}$	**2.00**	$\mathbf{1.44 \times 10^{-7}}$

6.3 Arriving freight trains

In total eight incidents are connected to freight trains arriving at a shunting yard, a private siding or a railway station (see Figure 8 and Table 26). Speeds found for arriving in the MISOS data set were all below 40 km/h.

Table 26 Incidents and wagons damaged for arriving freight train (Dutch dataset MISOS, 10 years).

Incident	Number of incidents	Wagons damaged	Average damage per incident
Derailment	5	12	2.40
Collision	3	4	1.33
Total set	**8**	**16**	**2.00**

Again, we use 7.82 million trains in the observation period of 10 year (Premise E), although this denominator is rather weak. The incident and damage frequencies of Table 27 are therefore initial.

Table 27 Incident and damage frequencies for arriving (Dutch dataset MISOS, 10 years).

Process	Incident frequency (per arrival)	Average number of wagons damaged per incident per 26.6 wagons	Damage frequency (wagons per arriving wagon)
Derailment	6.39×10^{-7}	2.40	5.77×10^{-8}
Collision	3.83×10^{-7}	1.33	1.92×10^{-8}
Total set	$\mathbf{1.02 \times 10^{-6}}$	**2.00**	$\mathbf{7.69 \times 10^{-8}}$

6.4 Sum of freight train processes

The case reports of European relevant leaks did not in all cases uniquely identify which of the processes was carried out at the moment of the incident, they had to be combined. To make a comparison between the Dutch damage frequencies of freight wagons and the relevant leaks of European incidents, we put transporting, arriving, departing, and waiting in the Dutch set in this Section together. The 55 incidents with freight trains and the 131 wagons damaged (Section 3.2) in these incidents (average 2.3 wagons/incident) are spread out over the performance of 1.12×10^{8} train km (Premise A). The resulting incident frequency is 4.89×10^{-7} per train km, the damage frequency equals 4.38×10^{-8} wagons per wagon km.

It should be noted the numbers in this section are specifically prepared for a comparison with the European relevant leaks to determine the outflow factors. The specific damage frequencies for the Dutch system are described more in detail in the earlier sections of Chapter 6.

6.5 Shunting operations with rakes of freight wagons

As discussed in Section 5.4, there are no denominator data to match the numerator data. Frequencies for shunting operations can only be derived with a very rough estimate of 1.13 million wagons for the year 2005, or 11.3 million wagons in the period 1996-2005. Section 9.2.2 briefly discusses initial indications of the shunting frequencies with respect to the current frequencies.

6.6 Summary and next steps

Table 28 gives the overview of failure frequencies for wagon damage of this Chapter. It is emphasised this is an interpretation of the Dutch registered cases of all kinds of freight in the period 1996-2005. All kinds of freight include ´relevant dangerous materials´.

Table 28 Dutch damage frequencies for wagon damage of freight trains for the observation period 1996-2005 (MISOS).

Process		Dutch wagon damage frequency	
Transporting	derailment (Table 22)	**2.24×10^{-8}**	per wagon km
	1—20 km/h	1.24×10^{-8}	per wagon km
	21—40 km/h	1.66×10^{-8}	per wagon km
	low speed	1.52×10^{-8}	per wagon km
	41—60 km/h	2.74×10^{-8}	per wagon km
	61—80 km/h	3.37×10^{-8}	per wagon km
	80+ km/h	3.49×10^{-8}	per wagon km
	high speed	3.23×10^{-8}	per wagon km
	collision (Table 23)	**0.602×10^{-8}**	per wagon km
	low speed	0.552×10^{-8}	per wagon km
	high speed	0.703×10^{-8}	per wagon km
	derailment+collision	**2.84×10^{-8}**	per wagon km
	low speed	2.07×10^{-8}	per wagon km
	high speed	3.93×10^{-8}	per wagon km
Departing	derailment	8.17×10^{-8}	per departing wagon
(Table 25)	collision	6.25×10^{-8}	per departing wagon
Arriving	derailment	5.77×10^{-8}	per arriving wagon
(Table 27)	collision	1.92×10^{-8}	per arriving wagon

The main weaknesses of this Chapter are the absence of speed denominators within transporting and suitable denominator data for shunting processes to derive shunting frequencies. It is recommended to gather such data. If the speed differentiation must be abandoned, the boldface figures can be used as generic damage frequencies.

The next step is to look at international failure frequencies of relevant outflow of toxic and flammable materials. These frequencies will be smaller than the ones derived for Dutch general freight wagons because the manifestation of relevant outflow is less common than general damage.

7 Leak frequencies for international cases

This Chapter describes failure frequencies for European incidents with relevant amounts of outflow of dangerous materials during transporting, arriving and departing. The numerators for this Chapter are defined in Chapter 4 and the denominators in Section 5.5.

The leak frequencies in this Chapter will be expressed in the unit of relevant leaks per wagon km. A thinkable alternative would be to derive frequencies in the unit of relevant incidents per train km. However, the performance cannot be expressed in the unit train km because it is not realistic that all trains are fully assembled with one type of dangerous materials only.

7.1 Class 3: flammable liquids

The Class 3 incidents form the most promising set to examine. For the wagon-based approach we use the following input:

- number of relevant leaks: 75 wagons (Table 17);
- performance: 967 million wagon km in Class 3 in year 2005 (Table 21);
- duration of period: 20 years (1985-2004, assuming the data of 2005 are representative for the entire period).

One gets the following leak frequency for Europe:

$$\frac{75}{967 \times 10^6 \times 20} = 3.88 \times 10^{-9} \text{ relevant leaks per Class 3 wagon km}$$

Taking only the nine countries which showed relevant Class-3 incidents, the denominator decreases and the frequency increases to 4.47 x 10^{-9} relevant Class-3 leaks per wagon km. This is considered an indication of the upper limit. However, we continue with the above-mentioned value 3.88 x 10^{-9} relevant leaks per wagon km. Note this frequency contains both incident types while a separation is possible between derailments and collisions[I].

Many of the speed indications for the 25 incidents are unknown. Only 11 of the Class-3 incidents have information on the speed of the train. There are too few incidents with speed indications to present different leak frequencies for low and high speed. Table 18 shows about twice as many leaks for high speeds (>40 km/h) compared to low speeds (6.0 versus 2.8). This would suggest a factor of about 2 between HS and LS based on less than half of the incidents. Besides, a robust derivation of speed-dependent leak frequencies can only be made when the performance (wagon km or actually train km) is subdivided in speed categories as well.

[I] The frequency 3.88 × 10^{-9} relevant leaks per wagon km contains derailments and collisions. It includes 2.79 × 10^{-9} (derailments) and 1.09 × 10^{-9} (collisions) relevant leaks per wagon km.

7.2 Class 2: gases

As mentioned before (Section 4.1), Class 2 comes with difficulties. The transport performance (the denominator) contains all sorts of dangerous gases instead of merely flammable and toxic gases which are relevant for our risk analysis and are included in the set of incidents. On top of that, the tank wall thickness for gas tanks is not a constant. Undoubtedly, thicker walls better resist external forces than thinner walls. Finally, there are only six gas incident cases; five of them probably had thin walls and one of them probably a thick wall. All in all, the limited amount of data and the uncertainty therein obstructs the accurate derivation of an international failure frequency for Class 2. Still, an attempt is made to get an impression of the order of magnitude for a Class 2 failure frequency.

For the wagon-based approach, we use the following input:

- number of relevant leaks: 11 wagons (Table 17);
- performance: 341 million wagon km in Class 2 in year 2005 (Table 20);
- 50% of this Class-2 performance is connected to relevant Class-2.1 and Class-2.3 gases (Section 5.5.1) (the 11 leaks concern those subclasses too);
- duration of period: 20 years (1985-2004, assuming data of 2005 are representative for the entire period).

One gets the following leak frequency for Europe:

$$\frac{11}{0.5\ \times\ 341\ \times 10^{6}\ \times 20} = 3.23 \times 10^{-9} \text{ relevant leaks per Class 2 wagon km}$$

Only one collision incident with Class-2 material is registered versus five derailments. Therefore there is no subdivision between these two incident types.

When more than 50% of Class 2 performance is relevant, the frequencies will decrease. The hypothetical minimum, following 100% of the gases are relevant, is half of what is calculated above.

7.3 Class 6.1: toxic substances

The problems with toxic liquid (Class 6.1) are discussed in Chapters 4 and 5. The main difficulty is there is not enough information on what inhalatory fraction of Class-6.1 performance to use, for oral and dermal toxicity are also present in this class. Furthermore, there is considerably less Class-6.1 transport compared to Class 2 and Class 3[m]. On top of that, the number of incidents (and leaks) of Class-6.1 wagons is according to Table 17 small. The ratio of either small or poorly derived numbers, i.e. the leak frequency for Class 6.1, is therefore unreliable. We therefore refrain from deriving a leak frequency for Class 6.1. This does not mean the leak frequency '6.1' equals zero[n]. The order of magnitude for the leak frequency is expected to be comparable to that of Class 3.

[m] For the Netherlands, the transport of Class-6.1 materials is 44 million tonne kilometre versus 162 million tonne km for Class 2 and 208 million tonne km for Class 3. For the 15 European countries, Class-6.1 material are 28% of Class 2 and 9.1% of Class 3.

[n] As an indication we compare Class 6.1 to Class 3 (both liquids) and we assume that 50% of Class-6.1 transport is relevant (only toxic by inhalation). The Class-6.1 performance is 22 times less (=1/(50%×9.1%)) than Class 3. Instead of 75 leaks of Class-3 wagons (Table 17), one expects 75/22 = 3.4 leaks of Class-6.1 wagons. This is rather close to the three leaks mentioned in Section 4.3. In other words, Class-6.1 frequencies are probably of the same order as those for Class 3.

7.4 Summary and next steps

This Chapter shows two failure frequencies from the European set:

- Class 3 (flammable liquids): 3.88 x 10^{-9} leaks per wagon km;
- Class 2 (toxic and flammable gases): 3.23 x 10^{-9} leaks per wagon km.

The failure frequencies for Class 2 include the assumption that 50% of the Class-2 performance is connected to gases which are not used in third-party risk calculations.

Now both the Dutch failure frequencies for general freight (Chapter 6) and European failure frequencies for relevant leaks of Class 2 and Class 3 (Chapter 7) are derived, we can turn to the comparison between these sets. This is carried out in Chapter 8.

8 Outflow factors: from damage to leak

This Chapter combines the results of Chapters 6 and 7. The connection between the two sets gives outflow factors. An outflow factor associates Dutch frequencies for general freight to the international frequencies for relevant leaks of flammable or toxic substances. The European leak frequency depends on the dangerous materials class and is assumed to be equal to the product of the class-specific outflow factor and the class-independent Dutch damage frequency:

$$LF_i = DF \times OF_i$$

with
LF_i = European leak frequency for Class *i*
DF = Dutch damage frequency (independent of class)
OF_i = outflow factor for Class *i*

Damage to a freight wagon with any kind of material does not necessarily mean that in case the freight wagon transported flammable or toxic materials, a leak of these materials would have occurred. It is a challenge to judge from the case reports of Dutch incidents if the freight wagon with non-dangerous freight was damaged to the extent that equivalent damage to a hypothetical tank would have led to a spill. If too many non-severe damages to general freight wagons are included in the Dutch set, this will have the effect a lower outflow factor is calculated. So in the end the difference between 'general damage' and 'severe leaks of relevant materials' is included in the outflow factors.

At the moment the estimates for outflow factors are only derived for processes carried out by freight trains. For shunting operations proper denominators are lacking and the European incidents concerning relevant leaks (numerator) are not presented in this report.

8.1 Class 3: flammable liquids

We start with LF_3 of 3.88 x 10^{-9} relevant leaks of Class 3 per wagon km (Section 7.1) and compare this to the Dutch damage frequency *DF* of 4.38 x 10^{-8} wagons damaged per wagon km (Section 6.4). The outflow factor OF_3 is 0.088 leaks per wagon damaged and this applies to all incident types[o]. This number does not contain speed as a parameter. Earlier, Table 18 suggested the average number of leaks per incident in Europe is roughly twice as high for high speed (LS = 2.8, HS = 6.0). The factor of about two is also suggested in the damage frequencies of Table 22 (LS = 0.68, HS = 1.44). The net effect of dividing the two more or less similar speed-dependent frequencies is a constant. Therefore, the outflow factor in this report is proposed to be speed-independent. This simplifies the model at this stage.

The outflow factor for flammable liquids (Class 3) is 0.088 leaks per wagon damaged. This factor is for processes carried out by freight trains. A speed dependency is already present in the Dutch damage frequencies.

[o] The value of 0.088 is for all incident types, while there is a difference between derailments and collisions. However, when the two types are examined separately, the ratios of international leaks and Dutch damage become 0.087 for derailments and 0.093 for collisions. These two figures are each based on less data than the total set of incidents. Probably, the difference between 0.087 and 0.093 is not significant.

The French dataset (2,700 anomalies with dangerous materials) gives a different way to arrive at an estimate for outflow of Class 3. During transport ('circulation') 872 Class-3 incidents or anomalies are registered. Eleven of these Class-3 events are typified as collision or derailment, and concerned mostly one wagon with Class-3 material. Only one wagon showed a breach larger than 50 mm. The other ten showed no breaches in the tank[p]. The outflow factor 0.09 (=1/11) does not contradict the value of 0.088 estimated above.

8.2 Class 2: gases

As discussed before, compared to Class 3, Class 2 is more challenging. The following Section contains several ways to derive an outflow factor for Class 2. Most of the clues are indirect evidence, sometimes relative to Class 3.

The failure frequency for relevant leaks of Class-2 transport LF_2 is estimated at 3.23 x 10^{-9} relevant leaks per wagon km (Section 7.2). We compare this to the Dutch damage frequency *DF* of 4.38 x 10^{-8} wagons damaged per wagon km (Section 6.4). The overall outflow factor OF_2 is 0.074 leaks per wagon damaged and it is proposed for both derailments and collisions (although only one collision occurred).

The outflow factor for gases (Class 2) is 0.074 leaks per wagon damaged. This factor is for processes carried out by freight trains. A speed dependency is already present in the Dutch damage frequencies.

Below we present indirect evidence and several analogies to support the estimated outflow factor of 0.074 for wagons transporting gases.

Preliminary results of the French dataset
The French dataset contains seven Class-2 derailments and collisions during transport, mostly concerning one wagon damaged containing dangerous material. One of the wagons showed a (small) breach. This suggests an outflow factor for Class 2 of about 0.14 (=1/7) based on incidents. This set is too small to draw a conclusion. If instead we turn to the 107 derailments and collision data for shunting operations of Class-2 materials, the outflow factor is derived from two leaking wagons as 0.019 (=2/107). This is comparable to the shunting data for Class 3 (3/124=0.024). Therefore, although the setting is different because shunting operations (always at low speed) are used instead of transporting and very few data are present, it gives an indication that Class 2 wagons are perhaps somewhat stronger. In other words, the outflow factor for Class 2 OF_2 is expected to be similar to or maybe only slightly smaller than OF_3.

Relative to Class 3: average number of leaks
Table 17 shows the average relevant leaks per incidents for Class 2 and Class 3. Although the number of wagons with a relevant leak is influenced by many other parameters (the number of wagons which carried Class 2 or Class 3 materials), it gives some kind of indication. It appears that in case of Class-2 incidents on average 1.83 wagons are leaking and for Class-3 incidents this average is higher at 3.00 wagons. The ratio of these averages is 0.61. An indication for the absolute reduction factor for outflow of Class 2 OF_2 is OF_3 x 0.61 = 0.054.

[p] Data are provided by SNCF/UIC and these are promising for further analyses. Also shunting operations ('manœvres') are included in this French set. From the 124 Class-3 events typified by a collision or derailment, one incident showed a breach in the range of 20-50 mm and two incidents showed breaches smaller than 5 mm. This suggests the outflow factor of Class-3 material during shunting operations is about 0.024 (=3/124); this is about four times smaller than the outflow factor for Class 3 during transport. Please note the relatively small amount of incidents.

Relative to Class 3: from damage to leak
The following alternative approach looks at the ratio of the total number of wagons damaged and the total number of relevant leaks (Table 29). The main downside of this approach is that the international set only contains serious incidents with relevant leaks. Incidents with wagon damage but no outflow are bound to occur as well, but it is certain that these less serious incidents will not be included in the international set of leaks. Therefore, we do not focus on the absolute ratios which are about seven times higher than 0.074 (Class 2) and 0.088 (Class 3).

Table 29 European set of incidents with number of wagons damaged and relevant leaks.

Class	Number of incidents	Number of wagons damaged	Number of relevant leaks	Ratio relevant leaks per wagon damaged
2	6	21	11	0.52
3	25	126	75	0.60
6.1	3	5	3	0.60
Total	**34**	**152**	**89**	**0.59**

Instead, we concentrate on the relative factor between Class 2 and Class 3. The ratio of the two factors will give an indication of the difference in strength of the construction. The ratio of Class 2 versus Class 3 of Table 29 is 0.52/0.60 = 0.88. If this reduction were realistic, the overall outflow factor for Class 2 OF_2 would become OF_3 × 0.88 = 0.077. This is in line with the earlier presented OF_2 of 0.074. However, a shortcoming of this approach is the tank wagons damaged are not necessarily all of the same class. For example, from the six Class-2 incidents, 11 Class-2 wagons leaked. But the number of 21 wagons damaged could have included other dangerous materials as well. However, this is not entirely clear from the incident reports.

The ratios for fluids Class 3 and 6.1 are similar at 0.6 but the Class-6.1 set contains only three incidents. It is not surprising these numbers are close, because both involve the transportation of unpressurised liquids.

Relative to Class 3: outflow in DNV-ERA set
Another hint is obtained by examining the DNV-ERA set of derailments. Table 41 (see Annex 2) contains derailments that involve dangerous materials. Eleven Class-2 incidents are identified; three of them had relevant leaks. Beware that this focuses on incidents instead of leaking wagons. An outflow estimate of 0.27 (=3/11) is derived for Class 2. For Class-3 incidents this becomes 0.33 (=5/15). These outflow factors should not be interpreted as absolute values however, since they are based on very few incidents. An indicative relative approach can however be followed: the ratio of the two outflow factors is 0.82 (=0.27/0.33). According to this approach, the outflow factor for Class 2 would be OF_3 x 0.82 = 0.072.

Relative to Class 3: comparison with road transport
Although rail transport and road transport of dangerous materials are not identical, it can be used as an indication as well. The manual for risk calculations for transport [HART11] shows the difference between outflow factors for atmospheric and pressure tanks for road transport is roughly 0.5. The numbers are based on analyses of road incidents at highways and roads with a maximum speed of 80 km/h. This suggests an absolute outflow factor for Class-2 tanks of OF_3 x 0.5 = 0.044.

8.3 Summary and next steps

In this Chapter, outflow factors were derived which link damage frequencies to actual leak frequencies. The results are:

- Class 3 (flammable liquids): 0.088 leaks per wagon damaged;
- Class 2 (only toxic and flammable gases): 0.074 leaks per wagon damaged.

These numbers are considered usable for both derailments and collisions. Note that these outflow factors are not a function of speed; the speed dependency is already included in the damage frequencies. Another important remark is that within Class 2 50% of the performance is considered relevant. If this percentage is higher (there is no firm indication for the shares between the sub-classes), the outflow factor for Class 2 will decrease.

Now that two generic outflow factors are derived, the next step is to link these numbers to the more detailed structure of the Dutch incident trees for the processes of the freight trains. This is carried out in Chapter 9.

9 Dutch leak frequencies

This Chapter combines the Dutch damage frequencies of Chapter 6 and the outflow factors of Chapter 8. The results are presented in incident trees with a number of branches. The resulting Dutch leak frequencies are compared to the leak frequencies currently in use [HART11].

9.1 Updated leak frequencies per process

9.1.1 Transporting

The outcomes of Section 6.1 are combined with the outflow factors for Class 2 and Class 3 (Chapter 8). An outline of the incident tree for transporting freight trains is shown in Figure 12. At the right-hand side eight leak frequencies are proposed for transporting Dutch freight trains.

The tree can be divided into many more branches by including all subtypes of collisions, more speed categories and multiple locations for speed factors. In addition, the switch factor is not quantified so far. If this is done in the future, branching will be much more extended. The challenge with a highly branched tree however is that the model gets more complex. Furthermore, each branch needs to be substantiated with enough factual data, which cannot be done with the present 10-year period of Dutch incident cases and the sometimes ambiguous European leak case descriptions.

One can argue whether the present entering of the speed factor and the circumstance that this appears only once in the tree is optimal. If possible, speed is also introduced at the level of 'incident frequency'. But for that we need more appropriate denominator data of rail performance[q]. Also at the level of 'outflow factor' one might anticipate a differentiation in speed. Higher speed will promote more severe loss, that is, more leaks. However, valid information on speed in the international outflow cases is lacking. It is suggested (Chapter 8) the speed factor for damage frequencies is comparable to the international leak frequencies. In consequence, the outflow factor relating these is speed-independent in this report.

9.1.2 Departing and arriving

Comparable to Figure 12 an incident tree for departing and arriving freight trains is shown in Figure 13. The unit of the leak frequencies are leaks per departure or arrival instead of per wagon km like in Figure 12. Please note the frequencies for departing and arriving depend on rough estimates of the denominators. According to the data, a speed factor does not show up in this tree.

9.1.3 Other processes

Because of the lack of denominators and outflow factor for shunting operations, no trees are shown here. The left-hand sides of the trees will follow the way the trees are presented in Figure 11 (page 35).

[q] In absence of those data it was suggested to split the branch at the level of 'incident frequency', one labelled with *x* and the other with (1 – *x*). At this point, this would make the tree unnecessarily complex.

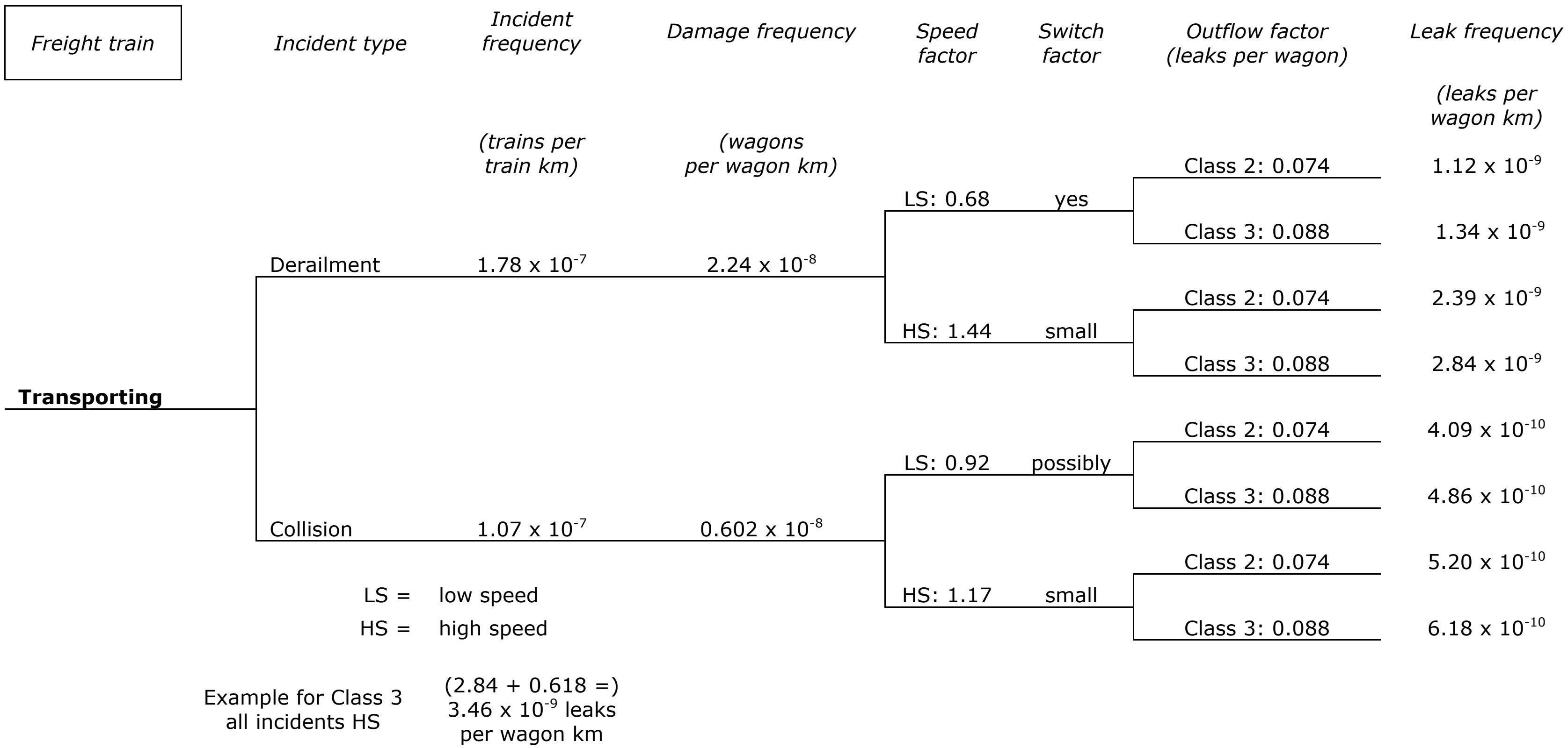

Figure 12 An outline of the incident tree for transporting freight trains. The speed factor occurs only at one level in the tree because of deficient denominator data. A comprehensive tree is expected to introduce speed at multiple locations in the tree. The switch factor cannot be quantified at this stage.

Freight train	*Incident type*	*Incident frequency*	*Damage frequency*	*Speed factor*	*Switch factor*	*Outflow factor (leaks per wagon)*	*Leak frequency*
		(trains per departure)	*(wagons per departing wagon)*				*(leaks per departing wagon)*
Departing	Derailment	1.28×10^{-6}	8.17×10^{-8}	no	yes	Class 2: 0.074	6.05×10^{-9}
						Class 3: 0.088	7.19×10^{-9}
	Collision	0.639×10^{-6}	6.25×10^{-8}	no	yes	Class 2: 0.074	4.62×10^{-9}
						Class 3: 0.088	5.50×10^{-9}
		(trains per arrival)	*(wagons per arriving wagon)*				*(leaks per arriving wagon)*
Arriving	Derailment	0.639×10^{-6}	5.77×10^{-8}	no	yes	Class 2: 0.074	4.27×10^{-9}
						Class 3: 0.088	5.08×10^{-9}
	Collision	0.383×10^{-6}	1.92×10^{-8}	no	possibly	Class 2: 0.074	1.42×10^{-9}
						Class 3: 0.088	1.69×10^{-9}

Figure 13 An outline of the incident tree for departing and arriving freight trains. Please note the frequencies for departing and arriving depend on rough estimates of the denominators. The switch factor cannot be quantified at this stage.

Calculation example of leak frequencies
In a certain area one anticipates a performance of 1 million wagon km with freight wagons transporting Class-2 materials, moving at high speed. Using the leak frequencies of Figure 12, the following numbers of leaks are expected. Derailments of freight wagons will give rise to 2.39×10^{-3} leaks, and collisions will give rise to 5.20×10^{-4} leaks.

9.2 Comparison to current leak frequencies

9.2.1 Transporting freight trains

It is emphasised there is no overlap between the Dutch case reports used in the 1995 studies [SAVE95a,SAVE95b] for the current frequencies and those of this study. Therefore, differences are expected to show up.

Table 30 shows the Dutch leak frequencies of the present study, using the broader speed categories low and high speed (LS and HS), as well as generic leak frequency without speed dependence.

Table 30 Damage and leak frequencies for transporting according to this report.

Speed	Damage	Outflow Class 2	Outflow Class 3	Class 2 leak	Class 3 leak
	(wagons per wagon km)			(leaks per wagon km)	
LS	2.07×10^{-8}	0.074	0.088	1.53×10^{-9}	1.82×10^{-9}
HS	3.93×10^{-8}	0.074	0.088	2.91×10^{-9}	3.46×10^{-9}
Generic	2.84×10^{-8}	0.074	0.088	2.11×10^{-9}	2.50×10^{-9}

Table 31 and Table 32 show the frequencies for high and low speeds, excluding and including a so-called switch surtax[r] as described in [SAVE95a] and more recently in [HART11].

Table 31 Failure frequencies excluding switch surtax according to [HART11].

Speed	Damage	Outflow Class 2	Outflow Class 3	Class 2 leak	Class 3 leak
	(wagons per wagon km)			(leaks per wagon km)	
LS	1.36×10^{-8}	0.00079	0.079	1.08×10^{-11}	1.08×10^{-9}
HS	2.77×10^{-8}	0.0028	0.56	7.76×10^{-11}	1.55×10^{-8}

Table 32 Failure frequencies including switch surtax according to [HART11].

Speed	Damage	Outflow Class 2	Outflow Class 3	Class 2 leak	Class 3 leak
	(wagons per wagon km)			(leaks per wagon km)	
LS	4.66×10^{-8}	0.00079	0.079	3.68×10^{-11}	3.68×10^{-9}
HS	6.07×10^{-8}	0.0028	0.56	1.70×10^{-10}	3.40×10^{-8}

[r] In the nineties of the previous century, a speed-independent, relatively large switch surtax of 3.3×10^{-8} per wagon km was introduced for 1-km zones containing at least one switch. It is not the intention of this report to reconstruct the derivation of two decades ago. In the present report no switch influence is introduced.

Table 33 Ratios of leak frequencies of previous tables for Class 2 and 3.

Switch surtax and speed		Ratio this study/HART	
		Class 2	Class 3
Excluding switch surtax	LS	142	1.7
	HS	37	0.22
Including switch surtax	LS	42	0.49
	HS	17	0.10

Table 33 shows the ratios of the previous three tables. Firstly, for Class 3 (flammable liquids) a low-speed (LS) zone without switches would, according to this study, have a ratio of 1.7 suggesting these zones are more risky than assumed up to now. Actually, these zones are expected to be less common, since an obvious reason to impose a lowered speed is the presence of switches. The other three ratios for Class 3 are below one. Probably the most representative ratios of Table 33 are 0.22 for HS zones (no switches) and 0.49 for LS zones (with switches).

Secondly, the ratios for Class 2 (gases) are more striking. They are all remarkably higher than one, up to over two orders of magnitude. The most probable ratios are 37 and 42, or roughly 40. Undoubtedly, uncertainties in the present study on Class 2 exist, but they do not correspond to the extreme ratios of Table 33. It should be remembered that in earlier days the outflow factors for gases were taken much lower at 0.00079 and 0.0028 leaks per wagon damaged instead of 0.074[s]. Because there were no Class-2 leaks (gases) observed in the Netherlands in the period covered by [SAVE95a], the authors used the outflow factors for Class-3 leaks (flammable liquids) and divided these by 100 and 200.

9.2.2 *Other processes: arriving, departing, and shunting*

The current incident scenarios and damage frequencies are described in [SAVE95b] and labelled with numbers 1 to 8 in [SAVE06]. Table 34 lists the current scenarios and frequencies. Three shunting scenarios (number 6, 7, and 8) are not regarded in this report. The way the damage frequencies are assigned earlier in [SAVE95b] is different: the units are (mostly) incidents per train, whereas the present study uses wagons as the main ingredient. It is not obvious how many wagons a train contains, and more essentially, how many wagons with dangerous materials are present in a train. Risk analyses for shunting yards are nowadays based on the input of the number of wagons with dangerous materials, and not on the number of trains. Therefore, these wagons are put into ‘effective trains’. It has been assumed [SAVE95b] an average train contains 20 wagons by default (for both freight trains and rakes of freight wagons). In consequence, the damage frequencies per train are divided by 20 and multiplied by the total number of dangerous wagons per year at a shunting yard (as shown in Table 35). Instead, we would prefer a number of 11.5 wagons per rake of freight wagons (Premise B) and 26.6 wagons per freight train (Premise C).

[s] It must be noted [HART11] also describes gas wagons which fail after external heating by a pool fire of a flammable liquid from a nearby leaking wagon: a ‘hot BLEVE’. Such domino effects are not considered in this report, but the future risk-calculation method should consider these effects.

Table 34 Description and damage frequencies of scenarios of [SAVE06].

Scenario and description		Damage frequency	
1A	Collision of two freight trains during arrival or departure (ATC in track)	5.5×10^{-7}	per train
1B	Collision of two freight trains during arrival or departure (no ATC in track)	5×10^{-6}	per train
2	Collision of an arriving or departing freight train with a rake of freight wagons	2.12×10^{-5}	per train
3	Unilateral incident (also for arriving and departing trains)	2.75×10^{-5}	per train
4	Traction change	1×10^{-6}	per change
5	Assembling (placing)	2.12×10^{-5}	per train
6	Shunting by gravity (not regarded in this report, see Section 3.3)	1.76×10^{-6}	per wagon
7	Intrinsic failure (not regarded, see Section 2.1)	5×10^{-7}	per wagon
8	BLEVE caused by fire (not regarded, see footnote s on page 65)	(equation)	

The descriptions of the incident scenarios and their frequencies of [SAVE06] can in some cases be interpreted in multiple ways. Several questions arose when attempting to reproduce the reasoning of two decades ago. This report proposes to use the processes as a basis, so a one-to-one comparison between the incident scenarios of [SAVE06] and the processes put forward in this study is impossible. However, we have tried to simulate each of the scenarios of [SAVE06] by the Dutch case data of 1996-2005.

We focus for the time being on the damage frequencies. Keeping in mind that authorised denominator data for shunting operations is absent, we use a rough estimate using the number of wagons that arrived and departed (Premises D and E in Section 5.3). Preliminary, indicative results for the ratios of the damage frequencies are briefly discussed here (Table 35). It is striking to see that the ratios vary from lower to higher than 1. This variability suggests some of the scenarios of [SAVE06] appear to be less important, that is less frequent, and others more important, that is more frequent, as assumed in [SAVE06]. At least, that is what has been recognised by categorising the Dutch incident cases on shunting yard for the time period 1996-2005.

Table 35 Preliminary comparison of damage frequencies for the scenarios of [SAVE06] simulated with incident cases of this report.

Frequency [SAVE06]	(per wagon)	Wagons damaged	Denominators (Premises of Chapter 5)	Frequency this study (per wagon)	Ratio this study/ [SAVE06]
1A	2.75×10^{-8}	8	B x E	3.85×10^{-8}	1.4
1B	2.50×10^{-7}	0	B x E	0	0
2	1.06×10^{-6}	9	B x E	4.33×10^{-8}	0.041
3	1.38×10^{-6}	29 + 170	B x E and B x D	1.51×10^{-5}	11
4	5.00×10^{-8}	2	unknown	?	?
5	1.06×10^{-6}	55	B x D	4.85×10^{-6}	4.6

The most striking feature of Table 35 is a higher frequency (factor of about 11) for the simulation of Scenario 3. This scenario encompasses unilateral incidents. Many derailments during 'shunting driving' occurred (170 wagons damaged), but also derailments of freight trains on arrival or departure need to be included in Scenario 3 (29 wagons damaged). These two ingredients use two different denominators to come to a damage frequency of 1.51×10^{-5} per wagon.

The collision of two freight trains during arrival or departure, Scenario 1A, is rather close to the current frequency when automatic train control (ATC) is present in the track. Both incidents did in fact happen with ATC present, so no incidents with Scenario 1B are found, and the ratio of the frequencies of this study and of [SAVE06] is zero.

Collisions between freight trains and rakes of freight wagons (Scenario 2) seem to be about 25 times less prominent according to the incident cases in the period 1996-2005. On the other hand, assembling (placing) (Scenario 5) is about 5 times more frequent than assumed in [SAVE06]. Earlier [SAVE06] determined one damage frequency which was assigned 50%-50% to Scenarios 2 and 5. However, the incident cases of 1996-2005 give the impression that splitting up would be more like 1%-99%.

The outflow factors of dangerous materials during shunting operations are also important here. The numerator for shunting incidents with significant outflow is not well investigated at this stage, and the denominator for international shunting operations with dangerous materials is unidentified. For liquids, a rough indication for the outflow factor on shunting yards is 0.024 according to the preliminary analysis of French data (see footnote p on page 588). This number is higher than the outflow factor of [SAVE06] of 0.01 (for most scenarios). This would introduce an extra increase of the leak frequency of Class-3 materials (flammable liquids) of about a factor of 2.4. More importantly, for Class-2 materials (gases) the indication of an outflow is 0.019 according to the preliminary analysis of French data. [SAVE06] proposes a much smaller outflow factor of 0.001 (for most scenarios). This would introduce an increase of a factor of about 20.

We emphasise the numbers presented in this Section are first indications.
Two main obstacles for a correct comparison are:

- the inferior quality of the denominator data for shunting operations;
- the absence of outflow factors for European shunting operations.

Therefore, this comparison should not be given too much weight at this moment. What can be stated however is that the interdependence of the damage frequencies according to [SAVE06] has not been observed in the Dutch incident cases of 1996-2005.

9.3 Summary and next steps

This Chapter showed incident trees for freight trains. It used the damage frequencies of Chapter 6 and the outflow factors of Chapter 8. At the right-hand side of the trees several new Dutch leak frequencies are proposed.

The resulting Dutch leak frequencies for transporting were compared to the current leak frequencies [HART11]. According to this evaluation the present study has about 2 to 4 times lower leak frequencies for flammable liquids (Class 3). The leak frequencies for gases (flammable and toxic of Class 2) are about 40 times higher than in the method in use in the Netherlands. This is explained by the low outflow factors for gases which were claimed in the past. The present investigations suggest outflow factors for gas wagons only slightly smaller than those for liquid wagons. In the past [SAVE95a] took the outflow factors of gas wagons two orders of magnitude smaller than those of liquid wagons. These large differences are still in the leak frequencies of [HART11] currently in use.

The following Chapter contains quantitative and qualitative information on uncertainties in the derivations and validation of the number of relevant leaks.

10 Uncertainties and validation

10.1 Quantitative indications of uncertainties

All conclusions so far have been derived on empirical basis and are presented by so-called point estimations. The confidence intervals around these point estimations can be, or should be, included for each calculation. Instead of a thorough statistical testing throughout the present report, we give some first indications of the uncertainties.

We start with a simplified approach of normal distributions. Around $p = \frac{k}{n}$ the uncertainty bounds can be calculated by its standard deviation σ_p:

$$\sigma_p = \sqrt{\frac{p(1-p)}{n}}$$

The 95% confidence interval around p is given by the lower and upper bounds:

$$p - 1.96\,\sigma_p\,, p + 1.96\,\sigma_p$$

The number 1.96 is the approximate value of the 97.5 percentile point of the normal distribution. As an example we take the Dutch damage frequency of Section 6.4 which is constructed from k=131 wagons damaged and from n= 1.12 × 10^8 train km × 26.6 wagons/train = 2.99 × 10^9 wagon km. Around the mean damage frequency p = 4.38 x 10^{-8} wagons per wagon km (Section 6.4) the lower and upper bounds encompassing the 95% confidence interval are 3.63 x 10^{-8} respectively 5.13 x 10^{-8}. The ratio between these upper and lower bounds is 1.41[t]. This factor can be seen as a range around the point estimation for the Dutch damage frequency used in the previous Chapters.

When both k and n are smaller, as for instance for the derivation of European leak frequencies of Chapter 7, the uncertainty increases, which gives rise to larger factors[u].

The failure frequencies written down in [SAVE95a,SAVE95b] use point estimations for the components in the trees like the one showed in Figure 12. It is strongly recommended that a future risk-calculation method incorporates statistical analyses, since uncertainties around scarce data can be large.

10.2 Qualitative indications of uncertainties

In the previous Chapters, several remarks were made on the uncertainties in the data set and the derivation of frequencies. This Section gives a qualitative

[t] This derivation is an approximation for it assumes normal distributions. Instead, we can use the inverse of the beta cumulative probability density function or a binomial distribution. The 95%-CI bounds shift slightly, but the factor between upper and lower bounds remains 1.41 (this drops to 1.13 using 50%-CI bounds).

[u] It is beyond the scope of this report to present such derivations. The reader is invited to prove the 95%-CI factors between upper and lower bounds for Class-3 leaks of 1.58 and for Class-2 leaks of 3.35 (50%-CI ranges: 1.17 and 1.51). It becomes more complicated when it comes to outflow factors, since they are constructed by combining the Dutch damage frequency and European leak frequencies. One can turn to Monte Carlo simulations to estimate an outflow range for Class 3 a 95% CI of 1.78 (50% CI of 1.22) and an outflow range for Class 2 a 95% CI of about 3.5 (50% CI of 1.5). Because the eventual Dutch leak frequencies are formed by a multiplication of several elements (as shown in for instance Figure 12), each with uncertainties and sometimes coupled, the overall uncertainty analysis becomes rather complex. It is suggested to carry out Monte Carlo simulations using the entire data set to arrive at quantitative indications of uncertainties.

overview of such uncertainties[v]. Indications of the possible direction are given; these are either an increase or a decrease of the leak frequencies, sometimes both directions are possible. Furthermore, an indication of the expected impact is included.

Section	Topic	Remarks	Possible direction (increase / decrease) and impact
3.1	Low number of incidents in the period 1996-1999 of MISOS	A higher number of incidents in the early years 1996-1999 will increase the Dutch frequencies. However, when an increased damage frequency is connected to the international leak frequency, the outflow factor will decrease.	- None
3.2, 3.3	Number of freight wagons damaged (MISOS)	In the documents for the 229 incidents, it is possible the definitions of wagon damaged are not identical.	- None
4	Completeness of international set of leaks	How well are these incidents registered, accessible, and documented? It is a challenge to obtain all relevant cases and case reports. On the other hand, it could contain incidents irrelevant for the (future) situation in the Netherlands. The net effect is estimated to be low.	↑ or ↓ Low
5.1	Assumed absence of empty wagons	If a fraction of the performance concerns empty wagons the outflow factors and the Dutch leak frequencies increase.	↑ Medium
5.1	Accuracy of performance in EuroStat	Difficult to address but we must accept that the EuroStat is as accurate as possible.	↑ or ↓ Low
5.1	Using the 2005 traffic performance data for all years	Data for the years before 2004 are not available.	↑ or ↓ Low
5.1.1	Using average number of freight wagons per train based on incidents (1996-2005) instead of one based on all regular traffic in the period	No proper registration of numbers of freight wagons in the regular situation is available. Using 26.6 wagons per freight corresponds to the value of 26.0 in [SAVE95a] (note SAVE95a used 20 wagons).	↑ or ↓ Low
5.3	Numbers of freight wagons arriving and departing (denominators)	Can hopefully be better enumerated for more recent periods.	↑ or ↓ High
5.4	Absence of proper performance data for shunting yards	Can hopefully be better enumerated for more recent periods. For this report we use the total number of freight trains which arrive or depart at shunting yards as a preliminary indication.	↑ or ↓ High

[v] We do not claim the uncertainties presented in this report embrace all possible uncertainties.

5.5.	Using Class-2 and Class-3 shares based on tonne km instead of train km	Class 2 and 3 performances are not available in the unit train km.	↑ or ↓ Low
5.5.1	Using estimate 50% of Class 2 performance is relevant	It is clear a significant portion of Class 2 considers non-relevant gases. If the share of relevant gases would be merely 25%, the Dutch leak frequencies for Class 2 become twice as high. If this share is 75%, they reduce by 0.66.	↑ or ↓ High
5.5.1	Using traffic performance for 15 European countries instead of only the traffic of 4 countries with Class 2 incidents	Will the fact that there are no records of incidents (numerators) in for instance Italy permit adding traffic of this country (denominators)?	↑ High
5.5.2	Using traffic performance for 15 European countries instead of only traffic of 9 countries with Class 3 incidents	Will the fact that there are no records of incidents (numerators) in for instance Italy permit adding traffic of this country (denominators)?	↑ Low
6.1	Presenting speed corrections in the Dutch damage frequencies instead of a generic frequency	The Dutch traffic performance does not contain speed as a parameter, but somehow influence of train speed on the damage must be accredited. Without speed corrections the damage frequencies are generic.	↓ (LS) ↑ (HS) Possibly high
7, 8	Speed-independent international leak frequencies and outflow factors	Too little information is available. However, the international data used does not contradict the speed correction suggested for the Dutch damage frequencies.	↑ or ↓ Possibly low
8	Linking Dutch damage frequencies to international leak frequencies	It is assumed the Dutch damage frequencies are applicable to all kinds of freight wagons, that is, including those carrying dangerous materials. The outflow factors automatically correct for imaginable dissimilarities between the two sets.	↑ or ↓ Low
8.2	Suggesting 0.074 as the outflow factor for Class 2	The figures suggest a range from about 0.04 to 0.1 leaks per wagons damaged. The central value and most direct estimates is 0.074. No distinction can be made for tank wall thickness.	↑ or ↓ Medium
9.9.1	Location of ‘speed factors’ in incident tree	In the incident tree for transporting the ‘speed’ branching follows after ‘incident type’ branching. A suggestion was made to insert the speed earlier, or even at multiple locations.	↑ or ↓ Unknown

9.2.1	Increase of a factor of ~40 for Dutch gas leak frequencies according to this study vs [HART11]	An earlier presented approach[w] using a relative proxy for European leaks following European wagon damage instead of European gas leak frequencies per wagon km showed a similar ratio	Probably none

The above-mentioned uncertainties indicate three main issues:

- The difficulty to obtain suitable denominator data for arriving, departing, and shunting in the Netherlands. Without proper data the derivations of damage frequencies for these processes are doubtful.
- The absence of the important parameter 'speed' in the denominator data. So far a speed correction factor is proposed at one location in the incident tree after the generic damage frequencies. If possible, this is done at the level of switch influence and outflow factors as well, in a more robust way.
- The use of data for both numerator and denominator information from other European countries. These data are not as precise and complete as the data for the Netherlands, but they are crucial for leak frequency estimates and therefore for outflow factors.

10.3 Validation: expected number of leaks

The updated Dutch leak frequencies of transporting freight trains presented in Section 9.2.1 (2.11×10^{-9} and 2.50×10^{-9} leaks/wagon km) are used to simulate the Dutch situation of relevant leaks for both gases and liquids. For the 10-year period 1996-2005, we take the following elements:

- traffic performance of 1.12×10^{8} train km (Premise A, Section 5.1);
- 26.6 wagons per train (Premise B, Section 5.1.1);
- a share of the total performance of 3.2 % for Class 2 and 4.1% for Class 3 (Section 5.5);
- a share of all Class-2 performance of 50% for relevant gases (Section 5.5.1);
- zero relevant leaks observed.

For the 25-year period the last element changes:

- one high-speed Class-3 incident (Boxtel 1989, see Annex 3) with 2 relevant leaks;
- zero Class-2 leaks observed.

Table 36 shows the expected numbers of leaks for the Netherlands for Class 2 and Class 3, based on leak frequencies currently in use and on those in this study. They are compared to the observed numbers of leaks in two periods.

Class 3: flammable liquids
The expected number of Class-3 leaks over 10 years equals 0.31 wagons ($=1.12 \times 10^{8}$ train km × 26.6 wagons per train × 0.041 Class-3 share × 2.50×10^{-9} Class-3 leaks per wagon km). This corresponds to the actual absence of leak (0 leaks) of flammable liquids in the 10-year period in the Netherlands. If we expand the period from 10 to 25 years by increasing the traffic performance by a factor 2.5, it covers the Dutch Boxtel incident. The expected number of Class-3 leaks grows to 0.77 leaks (first row of Table 36).

[w] Referring to RIVM letter 199/09 CEV Wol/2001+1875 of July, 9, 2009.

Table 36 Expected and observed numbers of leaks for the Netherlands.

Class	Study	Speed	Switch	Number of leaks 10 years	25 years
Class 3	This study	generic		0.31	0.77
		high speed		0.43	1.1
	[HART11]	high speed	excl. switch	1.9	4.8
			incl. switch	4.2	11
	observed			*0*	*2*
Class 2	This study	generic		0.10	0.25
		high speed		0.14	0.35
	[HART11]	high speed	excl. switch	0.0037	0.0093
			incl. switch	0.0082	0.020
	observed			*0*	*0*

Using the speed differentiation we propose to use the high-speed frequency of Section 9.2.1 instead of the generic leak frequency. The HS-leak frequency is estimated at 3.46 x 10^{-9} leaks/wagon km and the expected number of Class-3 leaks in 10 years becomes 0.43 leaks and 1.1 leaks in 25 years. Knowing all the reservations and extrapolations in the input parameters of this exercise, the latter is rather close to the real number of 2 leaks in 25 years.

In Table 36 the validation is also carried out for leak frequencies of [HART11] (see also Table 31 and Table 32). The expected numbers for zones without switches with high speed are a 10-year estimate of 1.9 Class-3 wagons and a 25-year estimate of 4.8 wagons. High-speed zones with switches give estimates of 4.2 (instead of 0) respectively 11 (instead of 2 leaks). This suggests too high current leak frequencies for Class 3 in [HART11].

Class 2: gases
The expected number of leaks of Class-2 wagons is 0.1 leaks (=1.12 × 10^8 train km × 26.6 wagons per train × 0.032 Class-2 share × 2.11 x 10^{-9} Class-2 leaks per wagon km) according to this study for the 10-year period. In fact, all numbers in the Section on Class 2 of Table 36 are close to zero. Those of the current frequencies of [HART11] are however smaller. Therefore, Class-2 incidents are checked for countries which experienced Class-2 leaks: France and Germany (Table 16). Table 37 shows the results of this simulation using the leak frequency derived for the Netherlands. This study, which is partially based on the input of France and Germany, suggests reasonable correspondence with the numbers of observed leaks. Using the Dutch leak frequencies of [HART11] predicts 0.12 and 0.16 leaks for France and Germany, which is lower than observed. This suggests too low leak frequencies for Class 2 in [HART11].

Table 37 Expected and observed numbers of Class-2 leaks for France and Germany.

Study	Speed	Switch?	France	Germany
This study	generic		1.5	2.0
	high speed		2.0	2.8
[HART11]	high speed*	excl. switch	0.054	0.075
		incl. switch	0.12	0.16
observed			*2*	*6*

* The low-speed numbers using [HART11] are five to seven times lower than those for HS.

10.4 Summary and next steps

This Section showed a great deal of uncertainty in the derivation of leak frequencies. It is difficult to give each point estimation based on the data a confidence interval. The future risk-calculation method should incorporate more quantitative indications of ranges than the present report.

Qualitative indications of the uncertainties are listed as well. There is a need for more detailed data of both the incidents and the different types of regular performance.

Finally, a relatively simple assessment of the number of leaks according to the derived leak frequencies and the number of observed leaks is put forward. More sophisticated statistical tests could however be used to validate the number of leaks. Although there are uncertainties in the derivation of new Dutch leak frequencies, the simulations of the Dutch, French, and German cases validate the present derivation of Dutch leak frequencies in this report.

The last step of this report is an overview of conclusions and recommendations.

11 Conclusions and recommendations

11.1 Conclusions

The results are based on incident cases of Dutch wagons damaged (1996-2005) and international relevant leaks (1985-2004). This Section describes the main outcome for 'transporting', 'arriving and departing' and 'shunting'.

Transporting

- New damage frequencies are estimated from Dutch derailments and collisions between trains in the period 1996-2005.
- Speed influence in these frequencies is proposed as well, but the performance (denominator) is not differentiated in speed categories because data are not available.
- The outflow factors are derived by the link with international set of relevant leaks for flammable liquids (Class 3: 0.088) and gases (Class 2: 0.074).
- Speed-dependent damage frequencies are multiplied by the outflow factors to obtain speed-dependent leak frequencies for the Netherlands.
- A comparison is made with the current frequencies of [HART11] for Class 3: the leak frequencies are about 2 to 4 times lower for high-speed zones without switches and low-speed zones with switches.
- A comparison is made with the current frequencies of [HART11] for Class 2: the leak frequencies could be about 40 times higher for high-speed zones without switches and low-speed zones with switches.
- The observed numbers of Class-2 leaks for the Netherlands, Germany, and France are better simulated by the proposed leak frequencies in this report than the currently used leak frequencies for gases of [HART11].
- There are uncertainties in the factor of for instance 40, but these signify presumably less than the factor itself.

The main contrasts with the currently used method [HART11] are:

- In [HART11] no distinction exists between the incident types: derailments and collisions are treated together.
- [HART11] contains a (substantial) surtax for the presence of switches; this cannot be appropriately calculated in this study without the numbers and types of passages of switches and without the certainty the switch was the culprit.
- The outflow factors in [HART11] for gases are not based on actual gas leaks and are very low at 0.0079 and 0.0028.

Arriving and departing

- Damage frequencies are estimated for Dutch cases 1996-2005.
- The numbers of arriving and departing trains for the Netherlands are not well known.
- Similar outflow factors are suggested for Class 3 (0.088) and Class 2 (0.074).

Shunting

- In this report the analyses are in terms of processes instead of incident scenarios as in [SAVE06].
- The numbers of wagons at shunting yards and the numbers and types of operations they underwent are still lacking.
- The simulation of incident scenarios [SAVE06,SAVE95b] cannot be properly performed without denominator data: but in a relative way the scenario frequencies according to [SAVE06] are not observed in the Dutch case incidents on shunting yards of 1996-2005.
- The outflow factors cannot be derived (no European denominator data; first estimates of French set are possible).

- The current outflow factors for shunting of [SAVE06], especially for gases, may be too low as well, based on first estimates of French data.

11.2 Recommendations

The following recommendations are made:

1. Register the yearly numbers of freight wagons with respect to distance travelled (divided to speed driven and track speed), switches passed, and shunting processes carried out. These denominators for the Netherlands, and probably for Europe are crucial for the derivation of more precise and more realistic failure frequencies.

2. Register incidents with greater detail. The interpretation of Dutch incidents would benefit from insertion of parameters such as speed during the incident, track speed, process of the train, external circumstances, involvement of switches and other infrastructural items, material transported, numbers of wagons transported, and numbers of wagons damaged, and to what extent. The case reports for international incidents with significant outflow of dangerous materials are insufficiently detailed as well. Information is collected in the context of Chapter 1.8.5 of RID, but this is inadequate to conduct analyses and risk assessment.

3. Instead of directly implementing the findings of this report in the current risk-calculation method (such as 2 to 4 times lower Class-3 leak frequencies and 40 times higher Class-2 leak frequencies), we recommend to define a project to develop a new risk-calculation method for transport of dangerous materials per rail. The input should be the results of this report, the results of the project of SAVE/Oranjewoud on measures, and other research documents on risk-calculation for transport per rail. The project should at least consider the following items (some of them not mentioned so far in this report):

   i. Speed is an essential parameter with respect to wagon damage and leaks, but in the performance no distinction can be made so far. Better estimates or genuine data are crucial to derive more sound speed-dependent failure frequencies.
   ii. Switches play a certain role in the incidents but before a switch surtax can be estimated, more information on the number of passages per type and position is needed.
   iii. Analyse 2,700 French anomalies with trains carrying dangerous materials (DNV is currently working on these data).
   iv. Correction for the fact that in several incidents more than one wagon leaks. In this report the outflow is based on wagons instead of incidents.
   v. Estimates of outflow factors for shunting (e.g. from the French data set).
   vi. Distinction between various outflow scenarios, such as instantaneous and continuous, various hole sizes.
   vii. Intrinsic failure (not connected to derailments or collisions).
   viii. Physical locality of scenarios (at/near shunting yards, 'hotspots', private sidings and so on).
   ix. Connecting the different processes to railway segments and legislation.
   x. Which phenomena occur and how: pool fire, flash fire, jet fire, toxic effect, cold/hot BLEVE.
   xi. Instead of merely calculating point estimations (the means) confidence intervals need to be included in the future risk-calculation method.

The framework for adjustments of the quantitative risk-assessment methods is described by members of the Dutch expert counsel risk analysis [DORA11]. In order to have access to as much relevant information as possible, it is proposed to involve all relevant parties in the working group of this future project.

The concluding recommendation is to keep in mind a risk-calculation model will always be a simplification of reality. Therefore, certain details are excluded. The question remains what to include and what to exclude from the risk-calculation model. If essentially relevant components are excluded, possibly because of the lack of data, there could be a chance the model will be too simple. On the other hand, if too much detail is included or actually desired and the essential data for such details are absent, the model may become too complicated or even incorrect.

Glossary

ARIA (Analyse, Recherche et Information sur les Accidents)	French accident database with accidental events which have or could have damaged health or public safety, agriculture, nature or the environment.
Arriving [process]	Arriving at a shunting yard, a station w/o shunting, or a private siding (typically carried out by freight trains).
ATC (Automatic Train Control)	A type of train protection system for railways that involves a speed control mechanism in response to external inputs.
ADR (Accord Européen relative au transport international de marchandises Dangereuses par Route)	European agreement concerning the international carriage of dangerous goods by road.
Class	Dangerous materials are divided into nine classes (in addition to several subcategories) on the basis of the specific chemical characteristics producing the risk.
Class 2	Class of gases which are compressed, liquefied or dissolved under pressure as detailed below.
Class 2.1	Flammable gases (sub-class).
Class 2.3	Toxic gases (sub-class).
Class 3	Flammable liquids (sub-class).
Class 6.1	Toxic substances (sub-class).
Damage	Detriment to a freight wagon transporting any kind of material without specific indication of severity; in this report, a conservative approach is used to include all kinds of damage.
Damage frequency	Number of (expected) wagons damaged per wagon or per wagon km.
Denominator	Number in a fraction placed below the line (vinculum) dividing the number above the vinculum.
Departing [process]	Departing from a shunting yard, a station w/o shunting or a private siding.

DNV (Det Norske Veritas)	Commercial company with the purpose of safeguarding life, property, and the environment.
DNV-ERA	Study carried out by DNV for ERA (2011); reference DNV11.
ERA (European Railway Agency)	European agency which sets standards for European railways.
FACTS (Failure and Accidents Technical information System)	Worldwide accident database which contains information on accidents involving hazardous materials or dangerous goods.
Failure frequency	Rate on which an engineered system or component fails; often expressed in a measure of time but for rail transport of freight, the failure frequencies have the unit incident, wagon damaged or leak per train (or wagon) movement, per train km, per wagon km, per train, or per wagon.
Freight train [train type]	Train including at least one locomotive and one freight wagon, with a train number.
GUNDI (Gefahrgut-Unfall-Datenbank im Internet)	German accidents database with dangerous materials during transport, handling, and storage.
HART (Handleiding Risicoanalyse Transport)	Dutch manual for risk analysis of transport of dangerous goods (draft, 2011); reference HART11.
HS (high speed)	Indicating speeds higher than 40 km/h.
Incident frequency	Rate with which incidents with freight trains occur.
Leak frequency	Rate with which relevant leaks of freight wagons filled with dangerous goods occur.
LoC (loss of containment)	A hazardous substance is released from the secure packaging.
Loose shunting [process]	Pushing uncoupled wagons which continue autonomously after traction of the locomotive stops.
LS (low speed)	Indicating speeds lower than 40 km/h
MISOS (Management Informatiesysteem voor Onregelmatigheden Spoorwegveiligheid)	Management Information System for Irregularities Railway Safety

Numerator	Number in a fraction placed above the line (vinculum) which is divided by the number below the vinculum.
Passenger train [train type]	Train consisting of at least one traction vehicle and in use for public transport.
Performance	Rate with which an engineered system or component fails; often expressed in a measure of time, but for rail transport of freight, the failure frequencies have the unit incident, wagon damaged or leak per train (or wagon) movement, per train km, per wagon km, per train, or per wagon.
Premise	Statement or proposition from which another is inferred or follows as a conclusion.
ProRail	Dutch organisation which takes care of maintenance and extensions of the national railway network infrastructure, allocating rail capacity, and traffic control.
Rake of freight wagons [train type]	Section of a train containing at least one freight wagon, with or without a locomotive, at a shunting yard
Rake of passenger wagons [train type]	Section with at least one passenger wagon, with or without locomotive, without passengers.
RBMii (Risicoberekeningsmal twee)	Government-owned Dutch software programme by AVIV for risk calculations for transport of dangerous goods by rail, road, and waterways.
Relevant leak	Loss of containment (LoC) followed by a relevant outflow of flammable or toxic materials in amounts posing in potency lethal injuries to civilians.
RID (Règlement concernant le transport International ferroviaire de marchandises Dangereuses)	European agreement concerning the international carriage of dangerous goods by rail.
RIVM (Rijksinstituut voor Volksgezondheid en Milieu)	Independent governmental Dutch research institute which performs tasks to promote public health and a safe living environment by conducting research and collecting knowledge.
SAFETI-NL	Commercial software programme by DNV for quantitative risk analyses of dangerous goods at industries, including shunting yards.

SAVE	Commercial engineering agency knowledgeable on risk and safety studies (in particular railways).
Shunting by gravity [process]	Composing or sorting trains by rolling freight wagons down a hump by gravity.
Shunting – driving [process]	Driving on a shunting yard or a private siding without the direct intention to compose or split trains.
Shunting – placing [process]	Shunting of freight wagons with the direct intention of placing a rake of wagons at another rake.
Shunting – splitting [process]	Splitting or pulling sets of freight wagons apart at a shunting yard.
Single locomotive [train type]	Solitary locomotive moving without wagons.
Switch (a.k.a. switch point, railway switch)	Mechanical installation enabling trains to be guided from one track to another.
Switch surtax ('wisseltoeslag')	A speed-independent, relatively large portion of the total wagon damage frequency allocated to 1-km zones containing at least one switch, amongst other things based on the prevalence of derailment incidents at or near switches (33%), introduced by [SAVE95a]
Track speed	Maximum speed allowed at the track at the time of the incident under the best of signal aspects.
Traction change [process]	Changing the traction vehicle, either the locomotive or its direction (carried out by (a) locomotive(s).
Train speed	Actual speed of the train driven at the time of the incident.
Transporting [process]	Transporting or transferring freight wagons from one place to another; the train is en route (typically carried out by freight trains).
Waiting [process]	Waiting of rakes of freight wagons (note a freight train with speed 0 km/h is labelled differently).
Work train [train type]	Train carrying freight exclusively for rail maintenance.

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Annex 1 MISOS set

This Annex contains the interpretation of the 229 Dutch incidents involving freight wagons from the MISOS dataset in the period 1996-2005. Only fields used in the examinations in this report are shown here.

DER = derailment; LAC = lateral collision; HOC = head-on collision; REC = rear-end collision; LXI = level crossing interaction; BSC = buffer-stop interaction
FRT = freight train; RAF = rake of freight wagons; SIL = single locomotive; WOT = work train; PAT = passenger train; RAP = rake of passenger wagons
TRA = transporting; ARR = arriving; DEP = departing; SDR = shunting – driving; SGR = shunting by gravity; SLO = loose shunting; SPL = shunting placing; STR = traction change; WAI = waiting

Number	Date	Year	Incident type	Train type1	Sub-process train1	Speed category train1 (km/h)	Number of wagons train11	Train type2	Sub-process train2	Speed category train2 (km/h)	Number of wagons train2	Number of wagons damaged train1	Number of wagons damaged train2	Sum of wagons damaged
1	23 Jan	‘96	DER	RAF	SPL	1-20	15					5		5
2	05 Feb	‘96	LAC	RAF	WAI	0	1	SIL	SDR	1-20	0	1	0	1
3	29 Feb	‘96	DER	FRT	DEP	21-40	25					1		1
4	13 Mar	‘96	DER	WOT	ARR	21-40	2					2		2
5	25 Mar	‘96	LAC	SIL	DEP	1-20	0	WOT	DEP	1-20	3	0	0	0
6	24 Apr	‘96	LAC	FRT	TRA	41-60	22	PAT	DEP	21-40	0	0	0	0
7	08 May	‘96	LAC	RAF	SDR	1-20	10	RAF	WAI	1-20	1	8	0	8
8	15 May	‘96	REC	WOT	WAI	0	0	WOT	other	1-20	1	0	1	1
9	04 Jul	‘96	DER	FRT	DEP	21-40	35					3		3
10	01 Aug	‘96	DER	RAF	SDR	1-20	33					1		1
11	05 Sep	‘96	DER	RAF	SPL	1-20	25					3		3
12	26 Sep	‘96	DER	FRT	ARR	21-40	32					4		4
13	08 Oct	‘96	DER	WOT	TRA	21-40	2					2		2
14	18 Nov	‘96	REC	RAF	WAI	0	6	RAF	SDR	1-20	6	3	0	3
15	18 Dec	‘96	REC	RAF	SPL	1-20	3	RAF	WAI	0	1	1	0	1
16	13 Feb	‘97	DER	FRT	TRA	21-40	49					3		3
17	14 Feb	‘97	DER	RAF	SDR	1-20	7					4		4
18	20 Mar	‘97	DER	RAF	SPL	1-20	18					3		3
19	20 Mar	‘97	LXI	RAF	SDR	1-20	6					0		0
20	03 Apr	‘97	LAC	FRT	TRA	80+	26	WOT	WAI	0	1	0	1	1
21	10 Apr	‘97	LAC	FRT	DEP	21-40	20	SIL	SPL	1-20	0	1	0	1
22	23 Apr	‘97	DER	FRT	ARR	1-20	25					2		2
23	26 Apr	‘97	DER	RAF	SDR	1-20	35					7		7
24	03 Jul	‘97	LAC	FRT	TRA	21-40	24	PAT	TRA	41-60	0	0	0	0
25	14 Oct	‘97	HOC	RAF	SPL	1-20	20	SIL	SDR	1-20	0	3	0	3
26	30 Oct	‘97	DER	RAF	SDR	1-20	8					1		1
27	02 Dec	‘97	DER	FRT	ARR	1-20	25					0		0
28	16 Feb	‘98	DER	RAF	SDR	1-20	2					2		2
29	19 Apr	‘98	BSC	RAF	WAI	1-20	20					1		1
30	19 Jun	‘98	DER	FRT	TRA	41-60	30					1		1
31	13 Jul	‘98	LAC	FRT	TRA	61-80	20	PAT	WAI	0	0	2	0	2
32	06 Aug	‘98	BSC	RAF	SPL	1-20	1					0		0
33	19 Aug	‘98	REC	RAF	SGR	0	1	RAF	SGR	1-20	5	1	0	1
34	31 Aug	‘98	DER	FRT	DEP	1-20	9					0		0
35	17 Oct	‘98	REC	RAF	WAI	0	11	SIL	SDR	21-40	0	2	0	2
36	21 Oct	‘98	REC	RAF	WAI	0	1	RAF	SDR	1-20	38	1	0	1
37	12 Mar	‘99	DER	FRT	DEP	1-20	35					2		2
38	30 Mar	‘99	DER	RAF	SDR	1-20	1					0		0
39	20 Apr	‘99	DER	FRT	TRA	21-40	19					1		1
40	20 May	‘99	DER	FRT	TRA	80+	34					18		18
41	26 May	‘99	REC	FRT	TRA	21-40	6	SIL	TRA	21-40	0	0	0	0
42	15 Jun	‘99	REC	RAF	WAI	0	32	RAF	SPL	1-20	17	4	0	4
43	29 Jun	‘99	DER	FRT	TRA	1-20	27					1		1
44	10 Jul	‘99	DER	FRT	TRA	41-60	32					10		10
45	15 Aug	‘99	DER	FRT	TRA	21-40	30					1		1
46	23 Nov	‘99	DER	RAF	SPL	1-20	30					3		3
47	09 Dec	‘99	DER	RAF	SPL	1-20	2					1		1
48	31 Jan	‘00	DER	RAF	SDR	1-20	10					2		2
49	01 Mar	‘00	DER	FRT	TRA	21-40	23					1		1
50	27 Mar	‘00	REC	RAF	WAI	0	1	SIL	STR	21-40	0	1	0	1
51	12 Apr	‘00	DER	FRT	TRA	1-20	10					2		2
52	20 Apr	‘00	DER	RAF	SDR	1-20	1					1		1
53	02 May	‘00	DER	RAF	SPL	1-20	42					2		2
54	03 May	‘00	REC	RAF	WAI	0	31	SIL	SPL	1-20	0	1	0	1
55	18 May	‘00	DER	FRT	DEP	1-20	19					3		3
56	31 May	‘00	DER	RAF	SDR	21-40	7					1		1
57	13 Jul	‘00	DER	WOT	SDR	1-20	1					0		0
58	18 Jul	‘00	DER	RAF	SDR	1-20	39					2		2
59	18 Jul	‘00	DER	RAF	SDR	1-20	19					2		2

Number	Date	Year	Incident type	Train type1	Sub-process train1	Speed category train1 (km/h)	Number of wagons train11	Train type2	Sub-process train2	Speed category train2 (km/h)	Number of wagons train2	Number of wagons damaged train1	Number of wagons damaged train2	Sum of wagons damaged
60	21 Jul	'00	DER	FRT	TRA	21-40	38					0		0
61	23 Jul	'00	DER	RAF	SDR	1-20	36					1		1
62	02 Aug	'00	DER	RAF	SDR	1-20	31					1		1
63	07 Sep	'00	DER	RAF	SDR	1-20	?					1		1
64	15 Sep	'00	DER	RAF	SDR	1-20	18					2		2
65	12 Oct	'00	DER	RAF	SDR	1-20	1					1		1
66	07 Nov	'00	DER	FRT	DEP	21-40	34					2		2
67	10 Nov	'00	DER	RAF	SDR	1-20	6					1		1
68	14 Dec	'00	REC	RAF	WAI	0	5	RAF	SPL	1-20	10	1	0	1
69	23 Mar	'01	DER	RAF	SDR	21-40	7					1		1
70	09 Apr	'01	DER	RAF	SGR	21-40	1					1		1
71	21 Apr	'01	DER	RAF	SDR	1-20	38					2		2
72	15 May	'01	DER	FRT	DEP	21-40	26					3		3
73	18 May	'01	DER	RAF	SDR	1-20	15					2		2
74	21 May	'01	LAC	FRT	ARR	21-40	22	PAT	ARR	21-40	0	3	0	3
75	05 Jun	'01	DER	RAF	SPL	1-20	20					0		0
76	08 Jun	'01	HOC	FRT	TRA	1-20	41	RAP	SDR	1-20	0	0	0	0
77	12 Jun	'01	DER	RAF	SDR	1-20	18					1		1
78	14 Jun	'01	DER	RAF	SDR	1-20	2					0		0
79	18 Jun	'01	BSC	RAF	SPL	1-20	35					1		1
80	08 Aug	'01	REC	RAF	SDR	21-40	21	RAF	WAI	0	1	2	1	3
81	14 Aug	'01	DER	RAF	SDR	21-40	17					2		2
82	15 Aug	'01	DER	RAF	SDR	21-40	32					2		2
83	20 Aug	'01	DER	RAF	SDR	1-20	36					1		1
84	06 Sep	'01	DER	RAF	SDR	1-20	10					1		1
85	10 Sep	'01	DER	RAF	SDR	1-20	28					2		2
86	22 Sep	'01	LXI	FRT	TRA	80+	18					1		1
87	11 Oct	'01	DER	RAF	SDR	21-40	26					2		2
88	26 Oct	'01	LXI	RAF	SDR	1-20	4					1		1
89	31 Oct	'01	DER	RAF	SDR	1-20	38					2		2
90	31 Oct	'01	DER	SIL	SDR	1-20	0					0		0
91	07 Nov	'01	DER	RAF	SDR	21-40	3					2		2
92	10 Nov	'01	REC	FRT	TRA	0	?	SIL	SDR	21-40	0	1	0	1
93	20 Nov	'01	BSC	RAF	SPL	1-20	10					1		1
94	26 Nov	'01	BSC	RAF	SPL	1-20	2					1		1
95	27 Nov	'01	LAC	FRT	DEP	21-40	21	PAT	DEP	21-40	0	5	0	5
96	30 Jan	'02	DER	RAF	SLO	21-40	1					1		1
97	16 Feb	'02	DER	RAF	SDR	1-20	12					1		1
98	16 Feb	'02	BSC	RAF	SDR	21-40	10					1		1
99	19 Feb	'02	DER	RAF	SDR	1-20	3					1		1
100	22 Feb	'02	BSC	RAF	SPL	1-20	12					1		1
101	26 Feb	'02	REC	RAF	SPL	1-20	18	SIL	WAI	0	0	0	0	0
102	27 Feb	'02	DER	RAF	SDR	1-20	3					1		1
103	06 Mar	'02	DER	RAF	SDR	1-20	2					1		1
104	13 Mar	'02	DER	RAF	SDR	1-20	5					1		1
105	18 Mar	'02	REC	RAF	WAI	21-40	9	SIL	WAI	0	0	0	0	0
106	28 Mar	'02	BSC	RAF	SPL	1-20	19					1		1
107	03 Apr	'02	DER	RAF	SPL	1-20	10					1		1
108	09 Apr	'02	DER	RAF	SPL	21-40	1					1		1
109	12 Apr	'02	DER	RAF	SDR	1-20	4					1		1
110	16 Apr	'02	REC	FRT	TRA	1-20	33	WOT	WAI	0	1	0	0	0
111	18 Apr	'02	DER	FRT	TRA	21-40	14					1		1
112	25 Apr	'02	DER	RAF	SDR	1-20	13					2		2
113	29 Apr	'02	REC	RAF	SGR	21-40	1	RAF	SGR	0	1	1	0	1
114	28 May	'02	LAC	RAF	SDR	1-20	30	RAF	SDR	1-20	20	3	2	5
115	10 Jul	'02	BSC	RAF	SPL	1-20	25					0		0
116	19 Jul	'02	DER	RAF	SGR	21-40	4					2		2
117	31 Jul	'02	DER	WOT	TRA	61-80	2					2		2
118	04 Aug	'02	DER	WOT	TRA	21-40	6					1		1
119	19 Aug	'02	DER	RAF	SPL	21-40	10					4		4
120	13 Sep	'02	DER	RAF	SDR	1-20	22					4		4
121	16 Sep	'02	DER	RAF	SDR	1-20	10					1		1
122	21 Sep	'02	DER	RAF	SLO	21-40	1					1		1
123	24 Sep	'02	DER	RAF	SPL	1-20	16					1		1
124	01 Oct	'02	DER	RAF	SDR	1-20	5					1		1
125	02 Oct	'02	DER	RAF	SPL	1-20	5					1		1
126	10 Oct	'02	LAC	FRT	TRA	21-40	44	RAP	SDR	1-20	0	4	0	4
127	01 Nov	'02	DER	RAF	SDR	1-20	11					1		1
128	04 Jan	'03	BSC	SIL	SDR	21-40	0					0		0
129	16 Jan	'03	DER	RAF	SDR	21-40	3					2		2
130	05 Feb	'03	DER	RAF	SPL	1-20	10					1		1
131	12 Feb	'03	DER	RAF	SLO	21-40	21					0		0
132	16 Feb	'03	LAC	FRT	TRA	61-80	34	PAT	TRA	80+	0	4	0	4
133	05 Mar	'03	REC	RAF	SDR	21-40	9	RAF	WAI	0	2	2	2	4
134	07 Mar	'03	DER	RAF	SPL	1-20	6					1		1
135	20 Mar	'03	HOC	FRT	TRA	21-40	11	PAT	TRA	21-40	0	0	0	0
136	07 Apr	'03	BSC	RAF	SPL	21-40	?					1		1
137	14 Apr	'03	BSC	RAF	SPL	1-20	7					1		1
138	15 Apr	'03	DER	RAF	SDR	1-20	2					1		1
139	24 Apr	'03	BSC	FRT	DEP	1-20	27					0		0

Number	Date	Year	Incident type	Train type1	Sub-process train1	Speed category train1 (km/h)	Number of wagons train11	Train type2	Sub-process train2	Speed category train2 (km/h)	Number of wagons train2	Number of wagons damaged train1	Number of wagons damaged train2	Sum of wagons damaged
140	30 Apr	'03	DER	FRT	TRA	61-80	21					10		10
141	01 May	'03	DER	RAF	SPL	1-20	1					1		1
143	28 May	'03	DER	RAF	SDR	21-40	?					1		1
144	04 Jun	'03	DER	FRT	ARR	1-20	25					3		3
145	06 Jun	'03	BSC	RAF	SPL	1-20	15					0		0
146	17 Jun	'03	DER	FRT	TRA	21-40	16					1		1
147	26 Jun	'03	DER	RAF	SDR	21-40	12					1		1
148	28 Jun	'03	DER	RAF	SDR	21-40	1					1		1
149	11 Jul	'03	LAC	FRT	DEP	1-20	26,5	SIL	SDR	1-20	0	2	0	2
150	24 Jul	'03	DER	RAF	SDR	1-20	14					3		3
151	28 Jul	'03	DER	RAF	SPL	21-40	24					1		1
152	07 Aug	'03	DER	WOT	SDR	1-20	1					1		1
153	09 Aug	'03	REC	RAF	SPL	1-20	1	WOT	WAI	0	1	1	0	1
154	08 Sep	'03	DER	RAF	SPL	1-20	?					2		2
155	01 Oct	'03	DER	RAF	SDR	1-20	2					1		1
156	16 Oct	'03	DER	RAF	SDR	1-20	7					1		1
157	19 Oct	'03	DER	WOT	TRA	1-20	40					0		0
158	20 Oct	'03	DER	RAF	SGR	1-20	?					1		1
159	18 Nov	'03	REC	RAF	WAI	0	2	SIL	SDR	21-40	0	1	0	1
160	01 Dec	'03	DER	FRT	DEP	21-40	35					1		1
161	04 Dec	'03	REC	RAF	WAI	0	2	SIL	SDR	1-20	0	1	0	1
162	05 Dec	'03	DER	FRT	TRA	21-40	22					4		4
163	12 Dec	'03	DER	RAF	SGR	1-20	4					2		2
164	06 Feb	'04	DER	RAF	SDR	1-20	2					1		1
165	09 Feb	'04	DER	RAF	SDR	1-20	3					1		1
166	11 Feb	'04	REC	RAF	WAI	0	1	RAF	SPL	21-40	1	1	0	1
167	16 Feb	'04	REC	RAF	WAI	0	1	RAF	SLO	1-20	3	1	0	1
168	23 Feb	'04	DER	RAF	SDR	21-40	22					1		1
169	02 Mar	'04	DER	RAF	SDR	1-20	13					1		1
170	02 Mar	'04	DER	RAF	SDR	21-40	?					1		1
171	05 Apr	'04	DER	RAF	SDR	1-20	9					1		1
172	05 Apr	'04	DER	RAF	SPL	1-20	18					1		1
173	22 Apr	'04	DER	RAF	SDR	1-20	1					1		1
174	06 May	'04	DER	RAF	SDR	1-20	24					1		1
175	17 May	'04	DER	RAF	SGR	1-20	1					1		1
176	18 May	'04	DER	RAF	SDR	1-20	18					2		2
177	27 May	'04	DER	RAF	SDR	1-20	29					0		0
178	10 Jun	'04	REC	RAF	WAI	0	1	RAF	WAI	1-20	1	1	1	2
179	13 Jul	'04	DER	RAF	SDR	1-20	2					1		1
180	14 Jul	'04	BSC	RAF	SPL	1-20	11					1		1
181	21 Jul	'04	REC	RAF	WAI	0	2	SIL	SDR	1-20	0	1	0	1
182	22 Jul	'04	DER	FRT	TRA	80+	17					2		2
183	04 Aug	'04	DER	RAF	SDR	21-40	10					1		1
184	08 Sep	'04	DER	RAF	SLO	21-40	1					1		1
185	09 Sep	'04	BSC	RAF	SPL	1-20	30					2		2
186	13 Sep	'04	BSC	RAF	SPL	1-20	20					1		1
187	16 Sep	'04	DER	RAF	SDR	21-40	?					1		1
188	17 Sep	'04	REC	RAF	SGR	0	3	RAF	SGR	21-40	4	3	1	4
189	24 Sep	'04	DER	FRT	TRA	21-40	27					0		0
190	27 Sep	'04	DER	RAF	SDR	1-20	28					0		0
191	04 Oct	'04	DER	FRT	ARR	21-40	43					3		3
192	13 Oct	'04	REC	RAF	SDR	1-20	17	SIL	WAI	0	0	2	0	2
193	08 Nov	'04	BSC	RAF	SDR	1-20	34					2		2
194	10 Nov	'04	DER	RAF	SDR	1-20	?					2		2
195	11 Nov	'04	REC	RAF	WAI	0	11	SIL	STR	21-40	0	0	0	0
196	15 Nov	'04	DER	WOT	SDR	1-20	0					0		0
197	01 Dec	'04	DER	RAF	SDR	1-20	1					1		1
198	17 Dec	'04	LAC	RAF	SPL	1-20	2	SIL	SDR	1-20	0	2	0	2
199	15 Jan	'05	DER	RAF	SDR	21-40	1					1		1
200	26 Jan	'05	DER	RAF	SDR	21-40	38					1		1
201	27 Jan	'05	DER	RAF	SDR	1-20	6					2		2
202	07 Feb	'05	DER	RAF	SDR	21-40	3					2		2
203	15 Feb	'05	REC	RAF	WAI	0	19	SIL	SDR	21-40	0	1	0	1
204	03 Mar	'05	REC	RAF	WAI	0	?	RAP	SDR	21-40	0	1	0	1
205	26 Mar	'05	DER	RAF	SDR	1-20	19					5		5
206	06 Apr	'05	DER	FRT	DEP	1-20	15					1		1
207	24 May	'05	REC	RAF	WAI	0	11	RAP	SDR	1-20	0	0	0	0
208	06 Jun	'05	DER	FRT	TRA	21-40	50					5		5
209	10 Jun	'05	DER	FRT	TRA	21-40	36					3		3
210	16 Jun	'05	DER	RAF	SDR	1-20	21					1		1
211	22 Jun	'05	DER	RAF	SDR	21-40	?					1		1
212	22 Jun	'05	DER	FRT	TRA	41-60	44					1		1
213	15 Jul	'05	DER	RAF	SDR	1-20	4					1		1
214	15 Jul	'05	DER	RAF	SDR	1-20	6					1		1
215	20 Jul	'05	REC	RAF	SGR	1-20	1	RAF	SGR	21-40	1	1	1	2
216	02 Aug	'05	BSC	RAF	SPL	1-20	10					1		1
217	16 Aug	'05	REC	RAF	SDR	1-20	8	RAF	WAI	0	2	2	0	2
218	24 Aug	'05	DER	RAF	SPL	1-20	4					1		1
219	01 Sep	'05	REC	FRT	DEP	21-40	50	RAF	WAI	0	2	3	1	4
220	09 Sep	'05	DER	RAF	SPL	1-20	6					2		2

Number	Date	Year	Incident type	Train type1	Sub-process train1	Speed category train1 (km/h)	Number of wagons train11	Train type2	Sub-process train2	Speed category train2 (km/h)	Number of wagons train2	Number of wagons damaged train1	Number of wagons damaged train2	Sum of wagons damaged
221	13 Oct	‘05	DER	FRT	DEP	1-20	11					1		1
222	30 Oct	‘05	BSC	RAF	SPL	1-20	33					1		1
223	25 Nov	‘05	LAC	FRT	TRA	21-40	7	FRT	TRA	21-40	19	4	2	6
224	08 Dec	‘05	DER	FRT	TRA	80+	28					2		2
225	15 Dec	‘05	DER	RAF	SDR	1-20	?					1		1
226	16 Dec	‘05	REC	FRT	ARR	1-20	30	RAF	WAI	0	1	0	1	1
227	17 Dec	‘05	REC	RAF	SGR	21-40	6	RAF	WAI	0	1	0	0	0
228	20 Dec	‘05	REC	FRT	ARR	1-20	?	SIL	WAI	0	0	0	0	0
229	19 Apr	‘02	REC	RAF	WAI	0	16	SIL	STR	1-20	0	1	0	1

Annex 2 DNV-ERA derailments

Sources for the incident reports are given in the original DNV report (Annex 1 to Part B [DNV11]). There is a considerable variation in information content of the different national incident reports which form the fundaments of the DNV-ERA set. This is due to the fact that a limited inquiry was made and not all resources were used. Sometimes it consists of merely a few lines in one of the less frequent European languages; at times very precise investigation reports are provided. For this report the original data sheet of DNV was improved at several locations. It may be concluded DNV had a different scope: it was more interested in determining the cause than in finding the two parameters of interest for the present study (speed and number of wagons derailed).

Although the inclusion of some cases might be reconsidered (no freight wagons derailed but only the locomotive) or for our purpose unusable cases with unknown numbers of wagons derailed at unknown speed, no cases are left out of the 201 original derailments. No cases are added either. An illustrative example that adding cases could be considered is the following. For the Netherlands the DNV-ERA dataset includes 4 derailments in the period starting April 30, 2003 to the end of 2005 (the other 4 are of more recent date). Nonetheless, the MISOS dataset includes 14 derailments of freight trains in the same period. This is explained by the fact that MISOS used a more comprehensive dataset. Probably other countries have such less accessible or even classified sets as well. To what extent derailments in other countries are overlooked by or not provided to DNV, cannot be quantified, at least not at this stage. Another remarkable case in point is that merely one derailment incident in Italy is included (Viareggio). This will probably not be a realistic representation of derailment incidents in a country much larger than the Netherlands.

It is suggested that a drawback of the present DNV-ERA study is that it turns out to be complex to obtain all relevant incidents from the different countries. Although the structure for gathering incident data is available (e.g. EU laws 2004/49, 352/09), the implementation is not yet complete. Many freight train derailments are possibly not noteworthy to be known, or at least to be published on the World Wide Web and so to become accessible for the rest of Europe. Therefore it is possible that derailments with freight trains have occurred without being included in the DNV-ERA set.

To summarise, the DNV-ERA set is not considered suitable for ‘absolute’ analyses such as the derivation of damage frequencies. However, for relative conclusions it will show to be useful.

Number of derailments
A large variation exists in the number of derailments per year in the 16-year spanning DNV-ERA set (Figure 14). Of course, there will be a natural variation which is partly linked to the economic situation, but Figure 14 suggests the DNV-ERA set is not complete. In some way this depicts the introduction of EC laws to harmonise definitions and incident reporting. On the one hand, several of the most recent incidents, starting at about 2009, are not included, for the reports were still being finalised at the time of composing the set. On the other hand, the number of incidents before 2000 is limited because it was the insertion of DNV to use generally recent, post 2000, derailments. Even without the Section up to 2000, it is striking that in the years 2000 to 2005 a relatively low number is noticed.

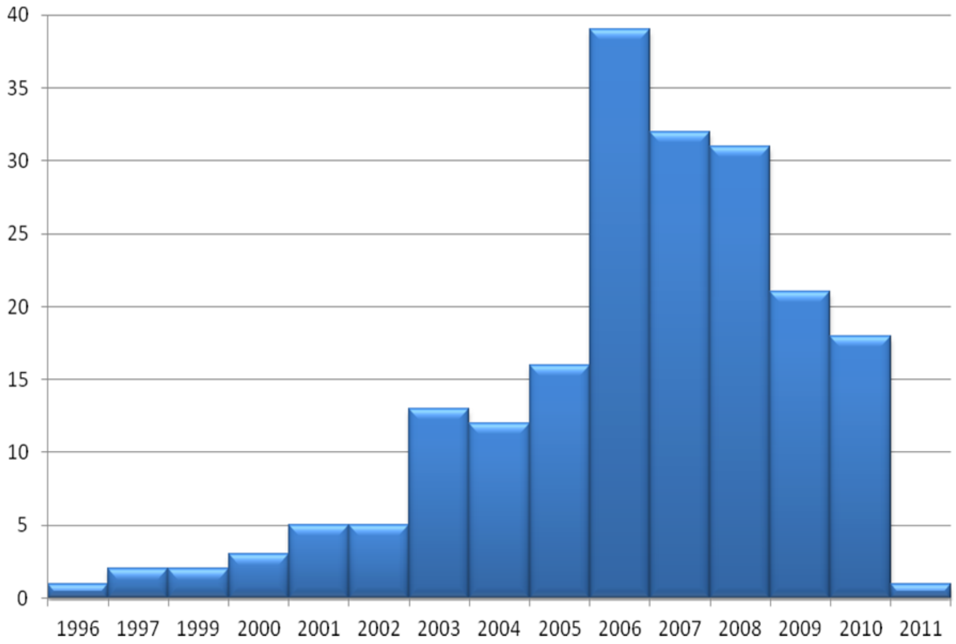

Figure 14 Number of derailments involving freight wagons in the period 1996-2011 (DNV-ERA).

Table 38 Number of derailments per country and speed category (DNV-ERA).

	Speed (km/h)						
Country	**1-20**	**21-40**	**41-60**	**61-80**	**80+**	**?**	***Sum***
Austria	2	14	3		5		*24*
Belgium		1	1				*2*
Czech Republic						3	*3*
Denmark				2		1	*3*
Estonia		1					*1*
Finland	5	7	1	3			*16*
France	2		1	1	2	3	*9*
Germany			2	3	2	25	*32*
Hungary	7		3	1		4	*15*
Ireland		1					*1*
Italy					1		*1*
Netherlands	1	4	1	1	1		*8*
Norway	3	5	1	3	1	4	*17*
Poland				1		5	*6*
Portugal						1	*1*
Romania	3					3	*6*
Slovakia						8	*8*
Spain		3		1	1	5	*10*
Sweden		2		3	2	1	*8*
Switzerland		7	2	2	1	1	*13*
United Kingdom	4	7	2		4		*17*
Total	**27**	**52**	**17**	**21**	**20**	**64**	***201***

Table 38 shows per country the number of derailments recorded as function of speed category. An interesting fact is that a large part of the German incidents (78% (=25/32)) were without speed indications. Furthermore, all the Slovakian incidents are without a speed category which makes them less useful for our purpose.

Number of wagons derailed
For the 201 derailments the total average is 3.93 wagons derailed per incident. It is interesting to have a closer look at the average number of wagons derailed per country (Table 39). The representation will certainly be biased by lack of harmonised definitions of a 'wagon derailed' and the dissimilarity in access to different national incident reports.

Table 39 Average number of wagons derailed per incident, country and speed category (DNV-ERA).

	Speed (km/h)						
Country	**1-20**	**21-40**	**41-60**	**61-80**	**80+**	**?**	***Sum***
Austria	2.00	2.14	3.00		4.80		*2.79*
Belgium		3.00	2.00				*2.50*
Czech Republic						2.33	*2.33*
Denmark				2.50		-	*2.50*
Estonia		6.00					*6.00*
Finland	3.40	3.43	8.00	5.33			*4.06*
France	1.50		4.00	4.00	10.00	3.00	*4.63*
Germany			10.00	13.67	12.50	4.00	*7.63*
Hungary	2.14		4.33	7.00		3.00	*3.13*
Ireland		6.00					*6.00*
Italy					7.00		*7.00*
Netherlands	2.00	2.25	9.00	10.00	1.00		*3.88*
Norway	1.33	2.00	17.00	7.33	5.00	2.50	*4.00*
Poland				4.00		3.00	*3.17*
Portugal						1.00	*1.00*
Romania	3.33					1.00	*2.17*
Slovakia						1.50	*1.50*
Spain		2.00		6.00	6.00	1.00	*2.86*
Sweden		4.50		6.00	14.50	1.00	*7.13*
Switzerland		4.14	2.50	1.00	2.00	2.00	*3.08*
United Kingdom	2.25	4.71	1.00		3.50		*3.41*
Total	**2.37**	**3.17**	**5.24**	**6.43**	**6.65**	**2.65**	***3.93***

For the Dutch derailments, the average number is 3.88 derailed wagons per incident (Table 39). Although it is a different, only partly overlapping, time span, this is higher than the average number in Table 8, where the average was 2.74. This can be explained by the selection of more severe incidents by DNV compared to the broader MISOS set. This supports the idea that DNV-ERA dataset in general consists of only the more significant or heavy incidents.

Because the number per country per speed category is almost certainly based on relatively small and sometimes questionable sets of incidents, one preferably refers only to the totals per speed category at the bottom of Table 39. It is evident the average number grows with speed, which is not unlikely. Table 40 shows the average number of derailed wagons per speed category. The total average is 4.28 now instead of 3.93 (as in Table 39). This is the result of excluding incidents with unknown speed.

Table 40 Number of incidents, wagons derailed, and average per speed category (DNV-ERA). The last column contains the relative factors normalised to 4.28.

Speed (km/h)	Number of derailments	Number of wagons derailed	Average	Relative
1-20	27	64	2.37	0.55
21-40	52	165	3.17	0.74
sub-total LS	*79*	*229*	*2.90*	*0.68*
41-60	17	89	5.24	1.22
61-80	21	135	6.43	1.50
80+	20	133	6.65	1.55
sub-total HS	*58*	*357*	*6.16*	*1.44*
Total	**137**	**586**	**4.28**	**1.00**

The relation between number of wagons derailed and speed is not necessarily linear. In fact, it is likely a more complex function connects these two. Both parameters have a maximum, i.e. speed will not become higher than say 140 km/h, and the number of wagons derailed will not be more than the number of wagons carried. Since the number of cases is (still) not big enough, we turn to speed categories instead of the speed itself. To summarise, although the DNV-ERA derailment set has weaknesses, it shows the growing average number of wagons derailed as a function of speed category for transporting. This supports the trend observed in MISOS (Section 3.2.1).

Dangerous materials involved
The last aspect of the DNV-ERA derailments set is the existence of derailments of freight trains which transported dangerous materials (DM). According to the DNV-ERA study the majority of the 201 incidents, a total of 159 incidents, are not connected to transport of DM. The other 42 (21%) derailments involved at least one freight wagon with dangerous material, according to DNV. For reporting (near-miss) incidents where DM were involved, there are strict RID guidelines (RID 1.8.5).

Leaks of dangerous materials
The way a DM leak is indicated in the report DNV-ERA is not similar to the definition used for the relevant European incidents (Chapter 4). The DNV-ERA set includes all kinds of leaks, most of them not severe enough to pose a threat to civilians. Table 41 gives an overview of our interpretation of the 42 incidents of the DNV-ERA set which included dangerous materials. Eight incidents were connected to the transport of an unspecified Class in the (brief) documentation.

Table 41 Number of incidents per DM Class and the interpretation whether the leak is considered relevant.

	Considered a relevant leak?			
DM Class	**no**	**yes, but empty**	**yes**	***Total***
Class 1.4	1			*1*
Class 2	7	1	3	*11*
Class 3	10		5	*15*
Class 6.1	1			*1*
Class 8	3		1	*4*
Class 2, 3, 8	1			*1*
Unknown	8			*8*
Not applicable	1			*1*
Total	**32**	**1**	**9**	***42***

Below follows the re-interpretation of the DNV-ERA dataset, containing derailments of freight trains in Europe (original source [DNV11]).

ID	Land	Date	Year	Place	Speed category (km/h)	Wagons derailed	Freight Carried	DM leak
NO-1	Norway	18 Jul	'02	Fetsund	21-40	1	DM	NS
NO-2	Norway	13 Aug	'02	Fetsund	21-40	1	DM	NS
NO-3	Norway	12 Feb	'03	Halden	21-40	3	No DM	N/A
NO-4	Norway	06 Jul	'04	Mo - Skonseng	1-20	1	iron Ore	N/A
NO-5	Norway	12 May	'05	Middagselv tunnel	41-60	17	iron Ore	N/A
NO-6	Norway	04 Dec	'05	Sandbukta	?	1	wood Chips	N/A
NO-7	Norway	23 Dec	'05	Bulken - Evanger	61-80	9	no DM	N/A
NO-8	Norway	06 Jul	'06	Råde – Onsøy	80+	5	empty	N/A
NO-9	Norway	26 Jul	'06	Dombås – Dovre	61-80	7	cars	N/A
NO-10	Norway	08 Sep	'06	Trettnes	?	8	N/A	N/A
NO-11	Norway	12 Dec	'06	Dombås station	1-20	2	no DM	N/A
NO-12	Norway	05 Sep	'07	Strømmen-Fjellhamar	?	1	work train	N/A
NO-13	Norway	29 Apr	'08	Skogn	21-40	2	N/A	N/A
NO-14	Norway	25 Jul	'08	Hval - Hønefoss	61-80	6	N/A	N/A
NO-15	Norway	12 Oct	'08	Halden station	21-40	3	timber	N/A
NO-16	Norway	25 May	'09	Ørtfjell station	1-20	1	ion Ore	N/A
NO-17	Norway	22 Dec	'09	Hauerseter-Fjellhamar	?	0	timber	N/A
SE-1	Sweden	22 Apr	'96	Kävlinge	61-80	9	ammonia	NS
SE-2	Sweden	04 Jul	'97	Kälarne	80+	15	DM	yes
SE-3	Sweden	08 Apr	'00	Borlänge	61-80	6	lpg	no
SE-4	Sweden	30 Mar	'01	Strosmbro	21-40	1	N/A	N/A
SE-5	Sweden	28 Feb	'05	Ledsgård	61-80	3	chlorine	no
SE-6	Sweden	29 Mar	'06	Linköping - Vikingstad	80+	14	timber	N/A
SE-7	Sweden	20 Jan	'08	Motala station	21-40	8	timber	N/A
SE-8	Sweden	21 Aug	'08	Kimstad station	?	1	N/A	N/A
FI-1	Finland	31 May	'03	Lahti station	61-80	1	N/A	N/A
FI-2	Finland	08 May	'04	Joensuu Station	21-40	1	timber	N/A
FI-3	Finland	11 May	'04	Pieksamaki Station	1-20	2	rails	N/A
FI-4	Finland	30 Jul	'04	Kouvola	21-40	2	N/A	N/A
FI-5	Finland	27 Apr	'05	Eskola	1-20	1	wood pellets	N/A
FI-6	Finland	28 Apr	'05	Heinävesi	1-20	5	timber	N/A
FI-7	Finland	13 Jul	'06	Tuupovaara - Joensuu	21-40	5	timber	N/A
FI-8	Finland	21 Mar	'07	Ylivieska railway station	21-40	1	N/A	N/A
FI-9	Finland	03 Jul	'07	Saarijärvi - Äänekoski	41-60	8	timber	N/A
FI-10	Finland	09 Mar	'09	Lahti railway yard	1-20	6	N/A	N/A
FI-11	Finland	17 Sep	'09	Kilpua station	21-40	5	wood pellets	N/A
FI-12	Finland	20 Mar	'06	Luumaki Station	1-20	3	N/A	N/A
FI-13	Finland	28 Dec	'05	Line Yppykkavarra - Vrtius	61-80	1	timber	N/A
FI-14	Finland	31 Oct	'05	Perasenia-joki Station	21-40	1	timber	N/A
FI-15	Finland	31 Jul	'03	Line Kallishti - Rantasalmi	21-40	9	timber	N/A
FI-16	Finland	16 Jul	'03	Line Hammaslahti - Tikkala	61-80	14	timber	N/A
DK-1	Denmark	03 Sep	'01	Hedenstad Station	61-80	4	empty	N/A
DK-2	Denmark	21 Oct	'04	Arhus	?	?	N/A	N/A
DK-3	Denmark	22 Feb	'05	Forlev	61-80	1	N/A	N/A
UK-1	United Kingdom	18 Oct	'05	Hatherley	80+	1	empty	N/A
UK-2	United Kingdom	18 Jan	'06	York station	41-60	1	N/A	N/A
UK-3	United Kingdom	21 Jan	'06	Waterside, East Ayrshire	21-40	6	coal	N/A
UK-4	United Kingdom	31 Jan	'06	Cricklewood Curve	1-20	2	aggregate	N/A
UK-5	United Kingdom	09 Feb	'06	Brentingby Junction	1-20	4	N/A	N/A
UK-6	United Kingdom	28 Jun	'06	Maltby North	21-40	3	coal	N/A
UK-7	United Kingdom	08 Sep	'06	Washwood Hheath	21-40	1	N/A	N/A
UK-8	United Kingdom	10 May	'07	Newcastle	21-40	4	empty	N/A
UK-9	United Kingdom	22 Jun	'07	Ely Dock	21-40	13	no DM	N/A
UK-10	United Kingdom	25 Feb	'08	Santon	41-60	1	coal	N/A
UK-11	United Kingdom	25 Mar	'08	Moor Street	21-40	4	empty	N/A
UK-12	United Kingdom	10 Aug	'07	Duddeston Junction	21-40	2	N/A	N/A
UK-13	United Kingdom	12 Jun	'08	Marks Tey	80+	1	N/A	N/A
UK-14	United Kingdom	27 Jan	'09	Stewarton	80+	6	DM	yes

UK-15	United Kingdom	01 May	‘09	Sudforth Lane	1-20	2	empty	N/A
UK-16	United Kingdom	25 Aug	‘09	Wigan North	1-20	1	empty	N/A
UK-17	United Kingdom	04 Jan	‘10	Carrbridge Station	80+	6	empty	N/A
IE-1	Ireland	10 Jan	‘08	Skerries	21-40	6	zinc	N/A
BE-1	Belgium	02 Sep	‘07	Ottignies	41-60	2	empty	N/A
BE-2	Belgium	29 Jan	‘08	Houyet	21-40	3	empty	N/A
NL-1	Netherlands	30 Apr	‘03	Apeldoorn	61-80	10	steel coils	N/A
NL-2	Netherlands	17 Jun	‘03	Halfweg	21-40	1	ammonia	NS
NL-3	Netherlands	06 Jun	‘05	Amsterdam	21-40	5	ballast	N/A
NL-4	Netherlands	10 Jun	‘05	Amsterdam	21-40	3	empty	N/A
NL-5	Netherlands	14 Sep	‘06	Dordrecht	21-40	0	DM	no
NL-6	Netherlands	23 Aug	‘07	Duiven	80+	1	iron ore	N/A
NL-7	Netherlands	22 Nov	‘08	Amsterdam	41-60	9	chalk	N/A
NL-8	Netherlands	29 Apr	‘10	Harmelen	1-20	2	no DM	N/A
DE-1	Germany	06 Aug	‘99	Bhf Lahr	?	2	DM	no
DE-2	Germany	21 Dec	‘99	Bahnhof Raubling	?	1	no DM	N/A
DE-3	Germany	22 Nov	‘00	Backnang	?	?	no DM	N/A
DE-4	Germany	15 May	‘01	Strecke Werl – Soest	?	?	no DM	N/A
DE-5	Germany	26 Jun	‘01	Strecke Biederitz – Güterglück	?	?	no DM	N/A
DE-6	Germany	16 Feb	‘02	Bhf Osnabrück	?	8	acrylnitril	yes
DE-7	Germany	16 Apr	‘02	Strecke Grafing – Kirchseeon	?	?	DM	no
DE-8	Germany	29 Aug	‘02	Bhf Ehrang (Trier)	61-80	4	cumene	yes
DE-9	Germany	24 Jan	‘03	Bhf Rommers-kirchen	?	?	no DM	N/A
DE-10	Germany	19 Feb	‘03	Strecke Kobern-Gondorf	?	?	no DM	N/A
DE-11	Germany	26 Jun	‘03	Line Dachau - Rohrmoos	?	?	no DM	N/A
DE-12	Germany	22 Oct	‘03	Strecke Hamburg Billwerder	?	?	no DM	N/A
DE-13	Germany	05 Mar	‘04	Bhf Hatzenport	?	?	no DM	N/A
DE-14	Germany	17 Mar	‘04	Bhf Osnabrück	61-80	20	DM	yes
DE-15	Germany	25 Oct	‘04	Bhf Merzig	?	?	no DM	N/A
DE-16	Germany	29 Mar	‘05	Bhf Schwindegg	?	1	DM	no
DE-17	Germany	10 Sep	‘05	Würzburg-Heidingsfeld	?	?	no DM	N/A
DE-18	Germany	18 Jan	‘06	Bhf Nienburg (Weser)	?	?	no DM	N/A
DE-19	Germany	15 Dec	‘06	Bhf Markt Einersheim	?	?	no DM	N/A
DE-20	Germany	21 Dec	‘06	Bhf Magdeburg-Buckau	?	?	no DM	N/A
DE-21	Germany	23 Jan	‘07	Elmshorn - Tornesch	80+	12	DM	yes
DE-22	Germany	28 Feb	‘07	Rotenburg Wümme	?	19	crude oil	NS
DE-23	Germany	12 Jun	‘07	Bhf Blankenberg (Sieg)	?	?	no DM	N/A
DE-24	Germany	22 Aug	‘07	Bahnhof Schwerte (Ruhr)	?	?	no DM	N/A
DE-25	Germany	19 Dec	‘07	Brannenburg - Raubling	80+	13	fireworks	no
DE-26	Germany	17 Jul	‘09	Bruchmülen - Bünde	?	1	DM	no
DE-27	Germany	07 Aug	‘09	Nürnberg Stein – Nürnberg Rbf	41-60	13	UN 3266	no
DE-28	Germany	25 Mar	‘10	Dinslaken – Oberhausen West	?	1	methanol	no
DE-29	Germany	16 Jun	‘10	Peine	41-60	7	no DM	N/A
DE-30	Germany	26 Jul	‘10	Bhf Falkenberg	?	2	no DM	N/A
DE-31	Germany	01 Sep	‘10	Bacharach	?	1	no DM	N/A
DE-32	Germany	20 Nov	‘97	Elsterwerda	61-80	17	DM	yes
AT-1	Austria	01 Mar	‘06	Salzburg	21-40	1	DM	no
AT-2	Austria	28 Apr	‘06	Salzburg	21-40	2	no DM	N/A
AT-3	Austria	09 May	‘06	Villach Sud	21-40	1	Diesel	no
AT-4	Austria	11 Jul	‘06	BHF Ebenfurth	1-20	3	no DM	N/A
AT-5	Austria	04 Oct	‘06	BHF Hieflau	21-40	2	no DM	N/A
AT-6	Austria	04 Apr	‘07	Scharding	80+	6	no DM	N/A
AT-7	Austria	02 Aug	‘07	BF Wien Matzleindorf	21-40	3	empty	N/A
AT-8	Austria	09 Sep	‘07	BHF Wien Donaukai	21-40	1	cars	N/A
AT-9	Austria	31 Oct	‘07	Tauern Tunnel	80+	2	DM	yes
AT-10	Austria	24 Mar	‘08	BF Leoben Donawitz	21-40	8	DM	NS
AT-11	Austria	16 Aug	‘08	BF Neuleng Bach	41-60	1	N/A	N/A
AT-12	Austria	06 Sep	‘08	BHF Rosenbach	21-40	1	N/A	N/A
AT-13	Austria	18 Oct	‘08	BHF Pochlam	21-40	1	N/A	N/A
AT-14	Austria	22 Oct	‘08	Wien Zvbf	21-40	2	iron ore	N/A
AT-15	Austria	31 Oct	‘08	Gummern	41-60	5	no DM	N/A
AT-16	Austria	17 Nov	‘08	Strecke Unter Purkersdorf	21-40	5	N/A	N/A
AT-17	Austria	20 Dec	‘08	Strecke 10102	80+	1	N/A	N/A
AT-18	Austria	08 Apr	‘09	Leithabrucke	21-40	1	N/A	N/A

AT-19	Austria	09 Apr	'09	St Peter Seiten	80+	3	N/A	N/A
AT-20	Austria	25 Jul	'09	Bruck Mur Graz	41-60	3	diesel	yes
AT-21	Austria	17 Apr	'10	Wakersbach Prambachkirchen	21-40	1	empty	N/A
AT-22	Austria	28 Apr	'10	Bhf Hohenau	21-40	1	no DM	N/A
AT-23	Austria	16 Jun	'10	Braz Arlbergstrec	80+	12	cars	N/A
AT-24	Austria	05 May	'10	Bf Selzhtal	1-20	1	iron ore	N/A
CH-1	Switzerland	06 May	'00	Rodi - Fiesso	?	2	no DM	N/A
CH-2	Switzerland	30 Mar	'04	Rodi - Fiesso	21-40	1	N/A	N/A
CH-3	Switzerland	19 Jan	'05	Chiasso Smista-mento	21-40	11	No DM	N/A
CH-4	Switzerland	08 Feb	'06	Amsteg	61-80	1	grain	N/A
CH-5	Switzerland	24 Mar	'06	Cornaux	21-40	1	N/A	N/A
CH-6	Switzerland	09 May	'06	Olten Rbhf	21-40	1	N/A	N/A
CH-7	Switzerland	26 Jul	'06	Brig entry to Simplon tunnel	21-40	8	N/A	N/A
CH-8	Switzerland	27 Jul	'06	Bresonnaz VD – Ecublens	41-60	4	N/A	N/A
CH-9	Switzerland	17 Aug	'06	Mühlehorn	61-80	1	N/A	N/A
CH-10	Switzerland	30 Sep	'08	Meilen – Herrliberg-Feldmeilen	41-60	1	ballast	N/A
CH-11	Switzerland	19 Jan	'09	Rbhf Limmattal	21-40	3	no DM	N/A
CH-12	Switzerland	13 Sep	'09	Basel Rangierbhf	21-40	4	N/A	N/A
CH-13	Switzerland	21 May	'10	Visp Station	80+	2	N/A	N/A
FR-1	France	18 Jan	'01	Montpellier station	1-20	1	N/A	N/A
FR-2	France	13 Jun	'06	Ferté-sur-Chiers	80+	1	iron ore	N/A
FR-3	France	21 Jul	'06	St. Parres le Vaudes Bar Seine	41-60	4	N/A	N/A
FR-4	France	24 Jan	'07	St. Amour – Beny Aiguille-Ipcs	?	5	no DM	N/A
FR-5	France	30 Oct	'07	Gex – Fort l'Ecluse-Collonges	?	?	no DM	N/A
FR-6	France	24 Nov	'09	Orthez	1-20	2	DM	yes
FR-7	France	22 May	'10	Neufchâteau	61-80	4	phenol	yes
FR-8	France	29 Jul	'10	Bully-Grenay station	80+	19	coal dust	N/A
FR-9	France	09 Mar	'11	Artenay	?	1	N/A	N/A
ES-1	Spain	07 Dec	'03	Valencia de Alcántara	?	?	DM	no
ES-2	Spain	15 Dec	'04	Pola de Lena station	21-40	2	DM	yes
ES-3	Spain	15 Mar	'06	Los Ramos Alqueiras	?	?	DM	no
ES-4	Spain	12 Dec	'06	Tarragona Termino station	21-40	1	DM	no
ES-5	Spain	29 Mar	'07	Montabliz	?	1	DM	no
ES-6	Spain	25 Jun	'07	Venta de Baños	?	1	no DM	N/A
ES-7	Spain	08 Jan	'08	Reus station	?	?	no DM	N/A
ES-8	Spain	24 Oct	'08	Moncófar station (Castellón)	80+	6	N/A	N/A
ES-9	Spain	17 Sep	'09	Zumarraga station	21-40	3	no DM	N/A
ES-10	Spain	14 Jun	'10	Cerdido y – Ortiguere, Coruna	61-80	6	timber	N/A
PO-1	Portugal	20 Dec	'06	Linha do Norte	?	1	cement	N/A
IT-1	Italy	29 Jun	'09	Viareggio	80+	7	butane gas	yes
HU-1	Hungary	10 Aug	'03	Budafok-Háros	41-60	8	crude oil	yes
HU-2	Hungary	15 Sep	'04	Fényeslitke	?	5	petroleum	yes
HU-3	Hungary	06 Aug	'06	Komarom Station	1-20	2	N/A	N/A
HU-4	Hungary	28 Oct	'06	Mende	41-60	1	no DM	N/A
HU-5	Hungary	07 Dec	'06	Debrecen	61-80	7	grain	N/A
HU-6	Hungary	27 Dec	'06	Lebeny Mosonszent	41-60	4	corn	N/A
HU-7	Hungary	25 Jan	'07	Szolnok	?	2	N/A	N/A
HU-8	Hungary	07 Feb	'08	Budafok	1-20	1	gasoline	no
HU-9	Hungary	26 Mar	'08	Kobanya	1-20	2	cars	N/A
HU-10	Hungary	22 Jul	'08	Rakos Station	1-20	4	N/A	N/A
HU-11	Hungary	09 Sep	'08	Szekesfeher	1-20	1	N/A	N/A
HU-12	Hungary	04 Feb	'09	Rajka Station	1-20	1	N/A	N/A
HU-13	Hungary	23 Mar	'09	Pusztaszabo	1-20	4	cement	N/A
HU-14	Hungary	21 Apr	'09	Vamosgyork	?	2	empty	N/A
HU-15	Hungary	15 Mar	'10	Miskolc Station	?	3	DM (empty)	no
RO-1	Romania	22 Feb	'07	Dej Triaj Station	1-20	8	N/A	N/A
RO-2	Romania	22 Feb	'07	Cricov Station	?	1	no DM	N/A
RO-3	Romania	15 Dec	'07	Milova	?	1	empty	N/A
RO-4	Romania	13 Mar	'08	Zavideni Station	?	1	iron oxide	N/A
RO-5	Romania	28 May	'10	Halmeu Station	1-20	1	coal	N/A
RO-6	Romania	18 Jul	'10	Aiud Station	1-20	1	pipes	N/A
CZ-1	Czech Republic	22 Feb	'08	Zabreh na morave	?	2	mixed	no

CZ-2	Czech Republic	24 Apr	‘09	Cercany Station	?	4	bulk	N/A
CZ-3	Czech Republic	21 Jan	‘10	Přerov - Prosenice	?	1	empty	N/A
SK-1	Slovakia	07 Oct	‘03	Ruskov	?	2	chlorine	no
SK-2	Slovakia	13 Apr	‘04	Velke Kostol’any – Piest’any	?	1	no DM	N/A
SK-3	Slovakia	27 Dec	‘05	Bratislava Vychod station	?	?	no DM	N/A
SK-4	Slovakia	30 Mar	‘06	Trnava – Kuty	?	?	no DM	N/A
SK-5	Slovakia	15 Sep	‘06	Zvolen - Plesivec	?	?	steel sheets	N/A
SK-6	Slovakia	27 Jul	‘07	Zohor – Plavecky Mikulas	?	?	no DM	N/A
SK-7	Slovakia	06 Sep	‘07	Lucenec – Zvolen	?	?	no DM	N/A
SK-8	Slovakia	04 Dec	‘07	Ziar nad Hronom	?	?	no DM	N/A
PL-1	Poland	10 Aug	‘07	Walbryzch Fabrycny	?	5	no DM	N/A
PL-2	Poland	23 Oct	‘07	Line 7 Lublin station	?	3	no DM	N/A
PL-3	Poland	17 Nov	‘07	Kalisz station	?	3	no DM	N/A
PL-4	Poland	25 Nov	‘07	Line 91 Zurawica station	?	3	coal	N/A
PL-5	Poland	16 Jun	‘08	Radziwillow - Miedniewice	61-80	4	coal	N/A
PL-6	Poland	10 Sep	‘08	Line no 65	?	1	DM	no
EE-1	Estonia	04 Dec	‘08	Rakvere, Kunda	21-40	6	no DM	N/A

Annex 3 Set of international relevant leaks

This annex shows the re-interpretation of the 34 incidents gathered by RIVM (from FACTS, ARIA, GUNDI, internet and RID working group) concerning relevant leaks during international transport of dangerous materials by rail. Only freight trains are included, with only flammable or toxic (by inhalation) gases and liquids. Collisions are merged (COL).

Number	Class	Year	Incident type	Location	Country	Train type1	Sub-process train1	Speed category train1 (km/h)	Train type2	Sub-process train2	Speed category train2 (km/h)	Leaks train1	Leaks train2	Sum of leaks
1	3	'89	DER	Boxtel	NL	FRT	TRA	60-80				2		**2**
2	2	'90	DER	Sint-Mariaburg	B	FRT	TRA	?				1		**1**
4	3	'91	DER	Stein-Säckingen	CH	FRT	ARR?	?				3		**3**
6	3	'90	DER	Chavanay	F	FRT	TRA	80+				9		**9**
12	3	'93	DER	La-Voulte-sur-Rhône	F	FRT	TRA?	20-40				4		**4**
13	3	'94	DER	Zürich	CH	FRT	TRA	60-80				8		**8**
23	6.1	'94	DER	Lausanne	CH	FRT	ARR	0-20				1		**1**
24	6.1	'94	DER	Amsteg	CH	FRT	TRA	60-80				1		**1**
27	3	'92	COL	Naestved	DK	PAT	WAI	0	FRT	ARR	?	1	0	**1**
28	3	'97	DER	Elsterwerda	D	FRT	ARR	80+				9		**9**
29	3	'97	COL	Frankfurt/M. Südbf.	D	FRT	TRA	?	FRT	TRA	?	0	2	**2**
34	2	'92	DER	Aix-les-Bains	F	FRT	ARR?	?				1		**1**
37	3	'97	COL	Hamburg-Kassel	D	PAT	TRA	20-40	FRT	TRA	20-40	0	3	**3**
50	2	'00	COL	Lillestrøm	N	FRT	WAI	0	FRT	ARR?	40-60	0	2	**2**
61	3	'02	DER	Osnabrück	D	FRT	ARR	?				2		**2**
66	3	'02	DER	Trier-Ehrang	D	FRT	TRA	60-80				2		**2**
69	6.1	'02	COL	Bad Münder	D	FRT	TRA	20-40	FRT	TRA	40-60	0	1	**1**
112	2	'04	DER	Osnabrück	D	FRT	ARR?	60-80				1		**1**
113	3	'04	COL	Monceau-sur-Sambre	B	FRT	ARR?	20-40	FRT	WAI	0	1	0	**1**
115	2	'96	DER	Schönebeck	D	FRT	TRA	?				5		**5**
116	3	'96	COL	Hagen Gbf Vorhalle	D	FRT	TRA	?	FRT	TRA	?	1	0	**1**
117	3	'96	DER	Waghäusel	D	FRT	TRA	?				1		**1**
119	3	'94	COL	Hassfurt	D	FRT	DEP	?	FRT	ARR	?	2	0	**2**
120	3	'85	COL	Hannover	D	FRT	TRA	?	FRT	TRA	?	2	0	**2**
121	3	'87	COL	Karslruhe	D	FRT	WAI	0	SIL	SDR	?	1	0	**1**
123	3	'91	COL	Partenstein	D	FRT	TRA	?	FRT	TRA	?	4	0	**4**
124	3	'91	COL	Oebisfelde	D	FRT	TRA	?	PAT	DEP	?	3	0	**3**
125	3	'87	COL	Lillle	F	FRT	TRA	?				1		**1**
126	2	'88	DER	St-Denis-de-Jargeau	F	FRT	TRA	?				1		**1**
127	3	'89	DER	Bréauté	F	FRT	ARR?	?	SIL	WAI	0	2	0	**2**
139	3	'86	DER	Rude	S	FRT	TRA?	?				3		**3**
140	3	'99	DER	Vainikkala	FIN	FRT	DEP?	20-40				7		**7**
146	3	'94	DER	Miramas	F	FRT	TRA	?				1		**1**
149	3	'93	DER	Zschortau	D	FRT	TRA	?	SIL	WAI	0	1	0	**1**

Annex 4 Freight train counts in the Netherlands for 2005

Counts of freight trains passing by, arriving at and departing from 'time table points' (Drglpt) for the year 2005. (Source: ProRail, PAV trein_op_emplacement 2005.)

Drglpt	Freight trains passing by	Freight trains arriving	Freight trains departing
Ah	11,966	23	18
Amf	9,097	2,224	2,190
Aml	3,937	1,788	1,663
Asd	7,756	542	545
Axa	0	778	518
Bd	25,602	254	265
Bet	21,477	0	0
Bot	18,956	3,098	2,927
Br	14,150	834	793
Btl	21,474	8	7
Bv	3,282	411	390
Bvhc	0	1,531	1,678
Ddr	30,227	273	271
Dn	15,698	10	3
Dv	5,567	29	27
Dz	0	498	480
Ehb	20,375	0	0
Ehv	20,340	41	40
Erp	17,720	1,534	1,534
Gn	1,868	43	45
Gp	4,672	0	2
Gz	25,609	1	3
Hea	6,751	1	1
Hgl	4,233	565	584
Hlm	3,556	59	49
Hln	4,667	6	0
Hm	15,714	1	0
Hrl	567	57	56
Hrt	15,703	4	2
Ht	9,503	655	645
Hze	4,672	0	0
IJsm	8,028	524	564
Kfh	10,279	7,071	7,281
Lpe	21,473	5	5
Lut	2,081	0	0
Lw	4	411	411
Mt	1,460	368	571
Mvt	0	6,322	6,487
Odb	7,774	3	2
Onn	4,184	2	1
Ot	18,705	0	1
Otb	7,050	0	0
Ps	23,328	418	407
Rm	5,814	23	31
Rsd	9,454	2,484	2,709
Rtd	11,924	57	64
Sloe	0	1,539	1,610
Srn	5,817	2	1
St	0	0	0

Std	6,226	739	633
Svg	1,716	1,024	781
Tb	26,565	49	44
Tba	22,722	1	1
Tbwt	25,605	9	7
Tnz	0	0	0
Ut	8,620	70	56
Utg	1,460	21	24
Utl	4,617	0	0
Vl	14,138	934	1,025
Whz	22,238	4,134	4,406
Wld	29,379	1	0
Wt	4,652	23	22
Zl	8,834	37	35
Zlw	29,857	708	693
Zp	596	21	19
Zv	11,599	90	74
Zvb	7,775	0	0
Zwd	30,683	92	107
Total	739,796	42,450	42,808

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RIVM report 620550010/2014

This is a publication of:

National Institute for Public Health and the Environment

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005530

December 2014