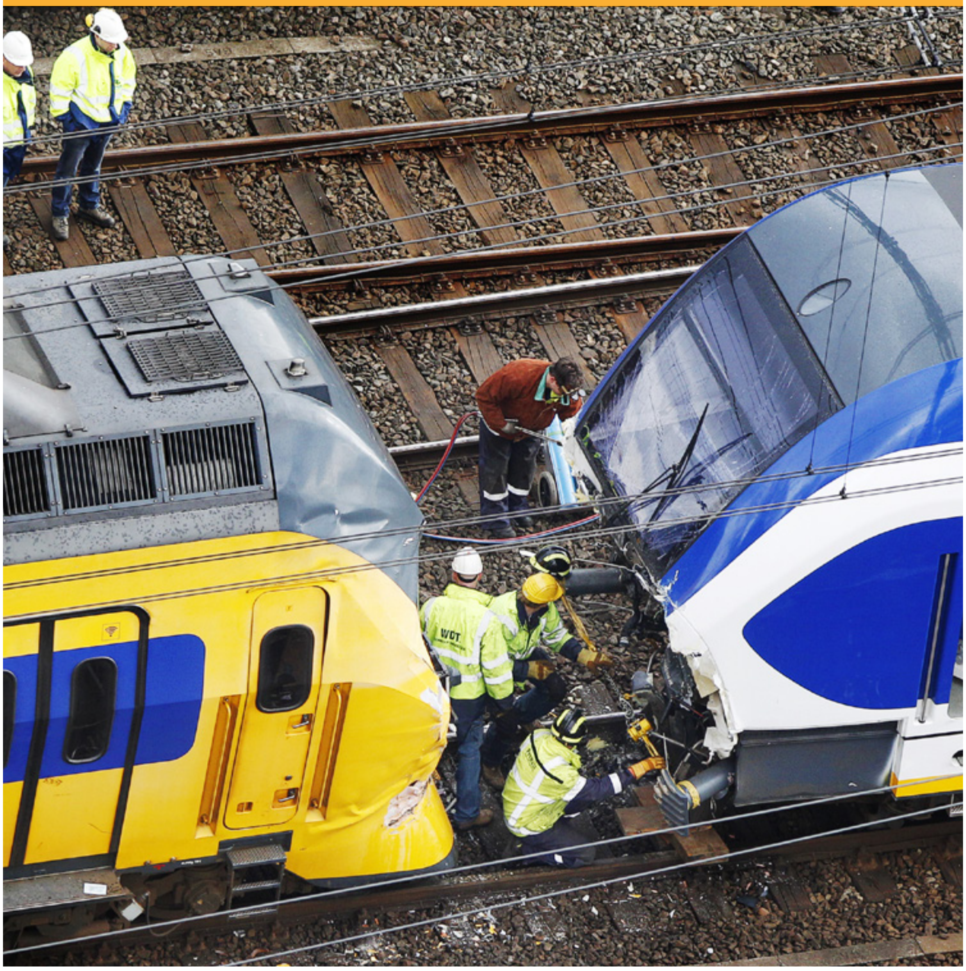
DUTCH
SAFETY BOARD

Train collision Amsterdam Westerpark



Train collision Amsterdam Westerpark

The Hague, December 2012

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Dutch Safety Board

The aim in the Netherlands is to reduce the risk of accidents and incidents as much as possible. If accidents or near-accidents nevertheless occur, a thorough investigation into the causes of the problem, irrespective of who is to blame for it, may help to prevent similar problems from occurring in the future. It is important to ensure that the investigation is carried out independently from the parties involved. This is why the Dutch Safety Board itself selects the issues it wishes to investigate, mindful of citizens' position of dependence with respect to public authorities and businesses. In some cases, the Dutch Safety Board is required by law to conduct an investigation.

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SUMMARY

On 21 April 2012 a train collision occurred in Amsterdam, near Westerpark. A sprinter and an intercity train collided head-on. At least 190 out of at least 425 occupants[1] were injured, of whom 24 were found to have sustained serious injuries. A day after the accident one of the seriously injured passengers died as a result of the injuries suffered.

The trains after the collision. Source: ANP-Jerry Lampen

Causes of the collision

The collision occurred as a result of the sprinter driving past a red signal. The driver of the sprinter had made an error in observing the red signal and thought that the signal had displayed yellow. The train driver subsequently failed to notice that he was passing the red signal because he had been distracted.

According to the Safety Board this was not the sole cause of the collision. Other circumstances also played a role. Engineering work was being carried out on the railway that day. Therefore, the timetable for that day had been adjusted and both trains were required to use the same railway track.

1 The Safety Board does not have any information about the exact number of occupants due to the fact that the numbers of occupants in trains are not registered.

In addition around that point in time a goods train had deviated from the timetable, as a result of which the approaching intercity train was unable to clear the railway track for the sprinter in time. The sprinter was therefore required to wait at a red signal until the intercity train had passed.

Not only the train driver did not notice that the sprinter had driven past a red signal, but traffic control and the safety systems similarly did not do so. The train driver therefore was not given any warning that he had passed a red signal, and the train was also not automatically brought to a standstill.

The causes of the train collision at Amsterdam Westerpark are not unique. The investigation shows that no one consciously acted contrary to the usual operating procedure. At the location and time of the collision the available technical systems were no different from those at many other locations in the railway network. This means that measures must be in place to ultimately prevent a collision from occurring as a result of adjusted timetables, delays and human errors. The Safety Board investigated the manner in which the parties involved controlled the risk of such a collision. The Safety Board also investigated what efforts the parties have undertaken to reduce the risk of injury among passengers and personnel as much as possible in the event of a collision. This summary contains the main conclusions drawn from the investigation.

NS and ProRail inadequately prevent red signals from occurring

The Safety Board concludes that NS and ProRail can increase their efforts to prevent red signals from occurring. NS had adjusted the schedule on account of engineering work. The schedule was tight and conflicted with the planning standards specified by ProRail, the infrastructure manager. This escaped ProRail's notice because ProRail relied on NS to adhere to the standard. This made the schedule unnecessarily vulnerable to disruption on the day of the accident and in practice gave rise to red signals.

ProRail, as the party responsible for traffic control, attaches low priority to ensuring that train running schedules are kept free of conflict (i.e. preventing yellow and red signals) until the time trains start operating. If a conflict arises, it is not detected by the systems. Whether solving conflicts is given priority, currently depends on the individual signaller (and his workload at that particular point in time).

NS does not guarantee that train drivers will fully focus their attention on the red signal

NS does not guarantee that after a train driver has passed a yellow signal, he will fully focus his attention on the subsequent red signal. And there is no technical device to alert the train driver that he is approaching a red signal, or to warn him immediately he has passed a red signal. In the past a support system was used to assist train drivers when approaching a red signal but it did not function sufficiently. Rather than improving this system, it was abolished.

If a train drives past a red signal, it goes unnoticed

ProRail does not guarantee that the options available are deployed to help prevent a train from driving past a red signal or to help limit the ensuing consequences. The signal was not fitted with Automatic Train Protection – Improved Version (ATB-VV), which automatically brings a train to a standstill at a red signal. Even a signaller does not have any adequate devices at his disposal to alert him to the fact that a train has driven past a red signal. Such a device was used in the past, but that system also failed to function sufficiently and was abolished. It has not been replaced by an improved functionality to date.

Crashworthiness: how is injury prevented in the event of a collision

During this investigation, it was the first time the Safety Board looked into the question of how the consequences for the occupants could have been limited. The Safety Board has also created a data set (for the purpose of additional investigations by manufacturers and other relevant parties) that provides information about the various aspects of the collision (collision dynamics, damage to the structure and interior of both trains and injury).

Even though the trains were involved in a forceful collision, they did not derail. No occupants became trapped. The injuries sustained by the occupants were mainly caused because they came into contact with the interior of the trains (such as seats, tables, glass partition walls and partition doors) and by coming into physical contact with other passengers. However, the cabin of the intercity train sustained severe deformation because, unlike the sprinter, the intercity train is not fitted with crash absorbers. Moreover the crash absorbers on the sprinter only had a limited effect because it collided with another train type.

It emerged during the investigation that when purchasing or overhauling trains, NS restricts itself to the concrete, minimum technical crashworthiness requirements prescribed by law. The aspect of interior crashworthiness was not considered when purchasing new trains. The railway undertaking also omitted to examine whether enhanced insights into crashworthiness gave cause to modify the structure of trains, for instance by ensuring that trains are 'compatible' in the event of a collision. The Safety Board concludes that NS has thus failed to perform its statutory duty of care for safety.

The investigation shows that it has taken longer than possible and advisable to improve the crashworthiness of passenger trains for both passengers and train personnel. The improvement efforts were affected as a result of the Minister of Infrastructure and the Environment not having incorporated the enhanced insights into interior crashworthiness in the passenger train admission requirements. The current crashworthiness regulations therefore do not match the current state of the art.

Railway undertakings' own responsibility and government supervision

The law requires that railway undertakings themselves determine what measures are appropriate to ensure they adequately control their safety risks. The investigation brought to light that they do not always do so in a manner enabling third-party review. And in day-to-day practice, this is not the focus of government supervision as performed by the Environmental and Transport Inspectorate.

CONSIDERATION

The train collision near Amsterdam Westerpark could have been prevented if the signal was fitted with Automatic Train Protection – Improved Version. Other measures could also have prevented the collision or have mitigated its effects. These conclusions are not new: the Safety Board has drawn the same conclusions in previous investigations. Since the head-on train collision near Eindhoven in 1992, the Safety Board and its forerunners have pressed for action in three areas: the implementation of an improved automatic train protection system (such as ATB-VV or ERTMS), clarity on the implementation timetable for such a protection system, and the adoption of additional measures for preventing collisions.

Improved automatic train protection (ATB)

Progress made on improving the ATB system between 1992 and 2004 can be described as slow. Improvements were limited to the implementation of a new system on regional railway lines that up until that time totally lacked ATB. On the main railway lines, which had been fitted with the first generation ATB, there were initially no improvements. In 2004, following an accident in Amsterdam, it was decided to develop and implement ATB-VV. Since 2009, ATB-VV has been installed on 1267 of the approximately 5000 signals eligible for improvement. This system, which is activated whenever a train is in danger of passing a red signal, is relatively simple and inexpensive to install: the installation of the first thousand ATB-VV-compliant signals cost fifty million euros. Since the implementation of ATB-VV, the number of passed red signals has fallen from more than 250 annually in the years 2000-2007 to above 150 in 2011. In 2012, upwards of 3500 signals are fitted with ATB First Generation, but not yet with ATB-VV. This number includes signals on busy routes, such as where the sprinter rode past the red signal. The Safety Board considers it a serious matter that a signal like this, located on a railway line with intensive train traffic, was not fitted with ATB-VV.

The installation of ATB-VV has until now been primarily based on the desired reduction of the number of passed red signals and the corresponding risks. Although this approach has borne fruit, it does not guarantee that the risks are controlled as effectively as is reasonably possible. It may be possible that even greater safety gains could be achieved with relatively moderate effort. To assess the potential gains, an analyse should be made of the advantages and disadvantages (costs and benefits) of possible future safety measures. It may be cost effective to install ATB-VV on more signals than is currently the case. ProRail has also announced its intention to fit all signals with ATB-VV. Furthermore, the Minister has expressed the intention to expand ATB-VV in the short term in the Long-Term Railway Agenda.

Time for measures

The Safety Board observes that there are also other measures to improve safety. One thing unites all these possible measures: it takes a long time before an actual decision is taken to implement a particular measure. The following examples from the investigation illustrate this.

The planning

The planning of the scheduled timetable is an important factor for rail safety. On 21 April 2012, too little time was included in the timetable to operate rail traffic in a conflict free manner. Trains were delayed and the scheduled timetable did not offer effective insight into how rail traffic would actually run. The current planning system is unable to detect such problems. The planning system has been almost fully replaced by a new system (DONNA). Development on the new system started in 2003 and it is expected to be fully rolled out in 2013. This system does detect conflicts, however on a fairly low level of detail. A separate system needs to be consulted to gain a more precise picture of the situation. It is striking that Germany, for example, developed and implemented a system in the period 1997-2003 that does provide a detailed picture. The Safety Board is astonished that DONNA lacks this degree of precision. It seems that the newly implemented system was not designed using the state of the art technology available at the time. It is essential for a busy rail network such as in the Netherlands that effective insight into the planned and actual traffic situation is available.

Other measures

The investigation has revealed that a number of various existent measures to help prevent collisions had not been implemented on 21 April 2012: conflict detection for signallers, support for drivers approaching a red signal and alerts for signallers when a train passes a red signal. In addition to the already acknowledged fact that they are necessary, these measures have two other things in common: all measures existed previously in one form or another. At the time however - roughly between 1990 and 2000 - these measures did not meet the requirements of the railway undertakings and they were abolished rather than being further improved. A positive current development is that NS and ProRail have since begun the concrete implementation of a number of the measures.

ERTMS

The decision-making process surrounding the implementation of the European train protection system ERTMS is also proceeding slowly. In the investigation into the train collision near Barendrecht (2009), the Safety Board established that other countries were taking decisions on the speed and manner of implementing ERTMS with greater dispatch than the Netherlands. Dutch implementation studies from 2003, 2007 and 2010 concluded that the costs and benefits were unclear and that more study was necessary. However, the Lower House Kuiken Committee concluded in early 2012 that the benefits of the system certainly outweigh the costs and that rapid implementation was both desirable and possible. Only after this pronouncement have concrete steps been made to prepare for implementation.

Crashworthiness
Also the area of crashworthiness is characterised by unnecessary tardiness. In the past few years much research has yielded new insights. Yet despite its relevant duty of care, NS has not utilised this information to improve safety when placing repeat orders for the intercity trains. The Safety Board is of the opinion that the Minister of Infrastructure and the Environment should only allow new trains to be ordered if they meet the latest technological standards current at the time, also in the case of repeat orders of older designs.

Railway undertakings' own responsibility and government supervision

The Railways Act requires that the railway undertakings record in their safety management systems the measures they are implementing in order to effectively control their safety risks. Railway undertakings are therefore required to define themselves how they will meet this open standard. The Minister of Infrastructure and the Environment has an important role to play in enforcing increasing rail safety. The Minister can, for example, apply pressure on railway undertakings when they fail to take worthwhile measures for controlling risks. This can be done when railway undertakings' safety management systems require approval (in order to be awarded certification in the case of both ProRail and the transport operators) and when enforcing the the instruments that were formulated in the safety management system.

The Safety Board is of the opinion that the railway undertakings should take all safety measures that are reasonably feasible, not only because law requires this, but also given the role they play in society. They should make transparent - also to those outside the rail sector – as to why they decide to implement certain measures or not.

NS and ProRail have conducted a joint investigation into the train collision and both intend to take a number of measures. Among other things, it appears that there will soon be clarity regarding how soon systems for preventing trains passing red signals (ATB-VV and ERTMS) are to be implemented. Furthermore, additional measures have been included in the Passing Signals Set at Danger Improvement Plan that the railway undertakings have jointly drawn up. The Safety Board esteems this development. Time will have to tell whether the present implementation of measures does actually proceed more expeditiously than has previously been the case. It is now up to the railway undertakings to put these measures in place swiftly and effectively.

The future

Taking everything into account, the Safety Board has determined that long decision-making and implementation processes seem to characterise the Dutch railway sector. This fact is all the more relevant today given that the policy of the Minister of Infrastructure and the Environment aims to stimulate even more intensive use of the rail network than is currently the case. It will become difficult to reconcile frequency and safety if measures aimed at further improving safety are not implemented.

Also the Minister of Infrastructure and the Environment has observed in the Long-Term Rail Agenda that the railways have become increasingly busy. She also states that cooperation within the rail sector has not kept pace with the increased complexity and sensitivity of the railway system. The Safety Board therefore considers it even more essential that the Minister[2] and the railway undertakings clearly elucidate their perspective on the relationship between safety, capacity and punctuality. In the view of the Safety Board, these interests do not always have to be at odds with one another. If trains are able to continue running smoothly this will benefit punctuality, capacity and safety (as well as passengers and shippers). A conflict in the execution of the scheduled timetable, as on 21 April, is a sign that punctuality, capacity as well as safety are adversely affected.

2 Since the second Rutte government took office on 5 November 2012, the Railway portfolio has been assigned to the State Secretary for Infrastructure and the Environment. This report was written taking account of the portfolio allocation at the time of the investigation.

RECOMMENDATIONS

The Safety Board has formulated the following recommendations.

Prevent trains from approaching yellow and red signals

1. **NS:** Ensure conflict-free scheduling, applying as a minimum requirement consistent compliance with the ProRail planning standards. In addition, perform systematic risk analyses to formulate measures - exceeding those set out in the planning standards - to ensure the safest possible schedule.

2. **ProRail:** ensure rail traffic is kept free of conflict during both scheduling and rail operations. This includes reviewing whether the schedule provided by the transport operators meets the planning standards, as well as identifying and resolving conflicts arising during rail operations in a reliable manner.

3. **Minister of, and State Secretary for Infrastructure and the Environment:** Focus on continuously reducing the number of conflicts during the actual operation of the timetable.

Prevent trains from driving past a red signal

4. **NS:** Prevent train drivers from from passing a red signal whilst not noticing this, by:

   a. implementing a system that issues a warning immediately when a train approaches or passes a red signal;
   b. employing more specific procedures in respect of a train driver's conduct after passing a yellow signal.

Prevent trains from colliding after a train has passed a red signal

5. **ProRail:** Ensure measures are in place:

   a. that warn signallers if a train drives past a red signal;
   b. to promptly switch signals to red for approaching or overtaking trains, if a train has driven passed a red signal.

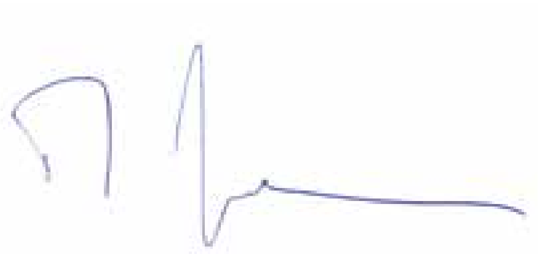
Prevent injury in the event of a collision

6. **NS:** Incorporate the crashworthiness of rolling stock in the safety management system, such that it is taken into account when considering the purchase or modification of trains, and to ensure that reasonably practicable improvements regarding safety will be implemented.

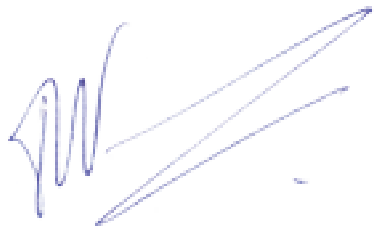
7. **Minister of, and State Secretary for Infrastructure and the Environment:**

   a. Incorporate the knowledge that is now available on interior crashworthiness in the passenger train admission requirements.
   b. At the same time expedite the further implementation of European regulations in this area.
   c. Ensure that re-ordered trains meet the requirements for newly built trains prevailing at the time the order is placed.

8. **Bombardier / Siemens:** Perform an additional investigation (in respect of both the train structure and the interior) and incorporate the lessons learned from this accident in future train designs.



T.H.J. Joustra
Chairman of the Dutch Safety Board



M. Visser
General Secretary

ABBREVIATIONS

AIS	Abbreviated Injury Scale
ALARP	As Low As Reasonably Practicable
ARI	Automatic Route Setting System (*Automatische Rijweginstelling*)
ARR	Train Event Recorder (*Automatische Ritregistratie*)
ATB	Automatic Train Protection System (*Automatische Treinbeïnvloeding*)
ATB-EG	Automatic Train Protection System – First Generation
ATB-NG	Automatic Train Protection System – New Generation
ATB-VV	Automatic Train Protection System – Improved Version
DOSV	Executive Consultation on Rail Safety (*Directieoverleg Spoorwegveiligheid*)
EC	European Community
ERA	European Railway Agency
ERRI	European Rail Research Institute
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
EU	European Union
GSM-R	Global System for Mobile communication - Rail
IGZ	Healthcare Inspectorate (*Inspectie voor de Gezondheidszorg*)
ILT	Human Environmental and Transport Inspectorate (*Inspectie Leefomgeving en Transport*)
IRM	Inter-regional rolling stock (*interregiomaterieel*)
ISS	Injury Severity Score
IVJ	Safety and Justice Inspectorate (*Inspectie Veiligheid en Justitie*)
IVW	Inspectorate for Transport, Public Works and Water Management (Inspectie Verkeer en Waterstaat)
KLPD	National Police Services Agency (*Korps Landelijke Politiediensten*)
NIB	National Investigation Body
NS	Dutch Railways (*N.V. Nederlandse Spoorwegen*)
NSA	National Safety Authority
OVS	Railway Undertakings Safety Consultation (*Overleg Veiligheid Spoorwegondernemingen*)

RAIB	Rail Accident Investigation Branch (United Kingdom)
RI&E	Risk Inventory and Evaluation
RIS	Rail Vehicle Admission Requirements (*Regeling Indienststelling Spoorvoertuigen*)
RKS	Rail Vehicles Inspection Regulations (*Regeling Keuring Spoorvoertuigen*)
RvTV	Dutch Transport Safety Board (*Raad voor de Transportveiligheid*)
SLT	Sprinter Lighttrain
STS	Stop signal (*stoptonend sein*)
TSI	Technical Specification for Interoperability
UIC	International Union of Railways
VIRM	Extended inter-regional rolling stock (*verlengd interregiomaterieel*)
VMS	Safety Management System (*Veiligheidsmanagementsysteem*)
VPT	Transport by Rail - integrated scheduling and planning rail traffic control system (*Vervoer Per Trein*)

1 INTRODUCTION

1.1 Reason for the investigation

On 21 April 2012 a train collision occurred in Amsterdam, near Westerpark. At least 190 people were injured in the collision, at least 24 of whom sustained serious injuries.[3] One person died of the injuries suffered a day after the accident. The Safety Board began an immediate investigation into the accident.[4]

The Safety Board is charged with establishing the causes of accidents and near accidents, the purpose of which is to learn lessons to help reduce the risk of such incidents recurring, or to help limit the consequences of such incidents. The Safety Board expressly does not seek to apportion blame as in the case of a criminal investigation. Instead, the Safety Board is most concerned with answering the key question: "What lessons can be learned from this train collision?"

1.2 Research question

The Safety Board established at the start of the investigation that the train collision occurred as a result of one of the two trains driving past a red signal.[5] This was taken as the starting point in formulating the research question.

The Dutch Safety Board assumes that if management, the governing body and the supervisory authority of the railway sector focus on controlling the risk of injury for rail passengers and personnel, they will identify and remedy an increased risk of collision. Based on the Amsterdam Westerpark accident the Safety Board has therefore examined what measures the parties involved had taken at that time to prevent collisions and subsequent injury. The key research question is as follows:

'How did the parties involved control the risk of a collision resulting from a train driving past a red signal, and how did they minimise the risk of passengers and personnel sustaining injury in the event of a possible collision?

3 Various sources provide conflicting information about the exact number of people injured. The figures contained in this report are based on the information known to the Safety Board. Appendix 1 elaborates on the data collected from the various sources. Appendix 7 explains what 'serious' injury is taken to mean in this report.

4 Pursuant to the European Railway Safety Directive (2004/49/EC) an independent party is required to conduct an investigation into rail accidents of a certain level of severity. In the Netherlands this duty lies with the Dutch Safety Board. The collision met the criteria for a mandatory investigation, in terms of both casualties and material damage. Incidentally, the Safety Board would have conducted an investigation into the accident regardless of the investigation requirement.

5 Several other possible causes have been excluded in Appendix 6.

This question can be broken down into two parts:

- How did the parties involved control the risk of a collision resulting from a train passing a red signal? (Chapter 3)
- How did the parties ensure that the risk of injury among passengers and personnel was minimised in the event of a possible collision? (Chapter 4)

Chapter 5 sets out the conclusions drawn from the investigation while Chapter 6 provides the recommendations.

1.3 Other investigations

NS and ProRail jointly conducted an investigation to determine the relevant facts and the immediate and underlying causes for the purpose of learning lessons from the accident. They have also formulated recommendations to prevent repetition of a similar accident. The NS and ProRail Executive Boards acted as the commissioning party for the investigation team.

The Environmental and Transport Inspectorate (*Inspectie van Leefomgeving en Transport*) performed an investigation to determine whether any breaches of the Railways Act took place, which contributed to causing the accident. The focus of their investigation was on the functioning of the NS and ProRail safety management systems. During the investigation the Inspectorate mainly examined the manner in which the adjusted timetable had been made. The Inspectorate's investigation therefore does not provide a complete picture of how the collision occurred, which is the subject of the Safety Board's investigation. As the Safety Board was already investigating the accident, the Inspectorate limited the scope of its investigation to establishing the breaches of the law on the basis of its powers and responsibility as the supervisory authority.

An investigation into the emergency response efforts carried out by the emergency services was not performed by the Safety Board. A joint investigation that was carried out by the Safety and Justice and the Healthcare Inspectorates focused specifically on casualty registration and triage.[6]

The introduction of the ERTMS train protection system has not been examined in this report. During its investigation into the Barendrecht train collision in 2009 the Safety Board already concluded that there was no clarity in the Netherlands about how soon the system would be implemented whereas there was clarity in many other countries.[7]

6 Triage is the assignment of degrees of urgency to injuries suffered by casualties of major accidents. The purpose is to decide which patients require medical treatment first and which patients are able to wait for medical treatment for a short or longer period of time.

7 Dutch Safety Board, 2011 Train collision at Barendrecht on 24 September 2009 and dealing with the issue of signals passed at danger.

In the report of the Lower House Kuiken Committee[8] submitted on 16 February 2012 the conclusion was drawn that it was also possible to implement ERTMS cost-effectively in the Netherlands and that there would be no need for any subsequent additional inquiry. The Council of Ministers took a decision in principle on 8 June 2012 to implement the system in the Dutch railway network. An overview is scheduled to be published in January 2013 containing the planning and sequence of implementation of ERTMS.[9]

1.4 Reference framework

The Safety Board applies five criteria to assess how the parties controlled their risks:[10]

1. The safety strategy is based on knowledge of the causal mechanisms for all risks.
2. The safety strategy is realistic and clearly documented.
3. The safety strategy has been implemented and is enforced.
4. The safety strategy is a management responsibility.
5. The safety strategy is continuously evaluated, and modified where required.

The parties are also required to work together to meet the above criteria. The parties not only carry individual responsibility, but they also have collective responsibility for the system as a whole. Parties are, for instance, required to collectively control the risks if one party is exposed to a risk which may have consequences for another party, or if the other party can specifically help to control the risk caused by the party that causes the risk.

1.5 Main parties and their responsibilities

This section summarises which parties played a role in this collision. A more detailed overview can be found in Appendix 5.

NS

NS provides public transport services in the Netherlands. The two trains that collided head-on at Amsterdam Westerpark, were operating under the responsibility of NS. In this context the responsibilities of NS included:

- the purchase and maintenance of trains;
- the staff to be deployed;
- the schedule (the timetable), for operating the trains as desired by the railway undertaking. NS submitted an application for the timetable to ProRail, which coordinated the desired timetable with the applications submitted by other transport operators.

8 Lower House of Dutch Parliament, year of session 2011-2012, 32 707, no. 9, Parliamentary inquiry into rail maintenance and innovation.
9 Letter from the State Secretary for Infrastructure and the Environment to the Lower House, 23 november 2012.
10 See Appendix 3 for more details of the reference framework.

ProRail

ProRail is charged with the duty of operating the Dutch railway network such that it can be used safely and effectively. To that end ProRail has three core tasks:

- *Building new railways and railway maintenance:* ProRail builds railways and maintains the railway infrastructure. In this capacity ProRail is responsible for ensuring the safe condition of the railways, such as the location of the railways and the position of signals and switches.
- *Scheduling and the allocation of capacity:* ProRail allocates infrastructure capacity to the various transport operators. Occasionally multiple transport operators apply for simultaneous use of the railway in their timetable applications. ProRail resolves conflicting timetable applications until a schedule has ultimately been drawn up that permits each transport operator to use the railway network at an agreed time.
- *Traffic control*: ProRail Traffic Control releases the railways to the transport operators so that they can use the railway network. The preference is to release the railway at the time agreed in the timetable. If this is rendered impossible due to disruptions or failures, traffic control may adjust the schedule.

Minister of Infrastructure and the Environment

Pursuant to the Third Framework Memorandum concerning Safety in Rail Traffic the Minister of Infrastructure and the Environment is charged with system responsibility for rail safety.[11, 12] This means that the Minister carries responsibility for the following:

- formulating policy;
- the functioning of the statutory frameworks;
- initiating new laws and regulations;[13]
- supervising compliance with the rail safety provisions set out in or under the Railways Act. The Minister has delegated this supervisory duty to the Human Environmental and Transport Inspectorate (ILT).

The Minister's role involves setting out frameworks. Under the Railways Act, railway undertakings are responsible for the safety of day-to-day operations within the frameworks defined in the Act. The railway undertakings have a statutory duty of care for safety. The railway undertakings must individually and collectively ensure that the safety risks are adequately controlled by taking appropriate measures. The Third Framework Memorandum concerning Safety in Rail Traffic,[14] which sets out government policy on railway safety, elaborates on what this means.

11 Ministry of Transport, Public Works and Water Management, Transporting safely, working safely, living safely with the railways (V*eilig vervoeren, veilig werken, veilig leven met spoor*). Third Framework Memorandum concerning Safety in Rail Traffic, June 2010 p. 24 (Lower House of Dutch Parliament, year of session 2009-2010, 29 893, no. 106).

12 According to the 2012 Government Agreement, rail traffic falls to the State Secretary for Infrastructure and the Environment in the Rutte II government. As this report describes the situation prior to the entry into force of the Government Agreement, 'the Minister of Infrastructure and the Environment' is used throughout this report.

13 An overview of the relevant legislation is included in Appendix 4.

14 Ministry of Transport, Public Works and Water Management, *Safety on the rails (Veiligheid op de Rails). Second Framework Memorandum concerning Safety in Rail Traffic*, November 2004 (Lower House of Dutch Parliament, session year 2004-2005, 29 893. nos. 1 and 2); Ministry of Transport, Public Works and Water Management, Transporting safely, working safely, living safely with the railways (*Veilig vervoeren, veilig werken, veilig leven met spoor*). *Third Framework Memorandum concerning Safety in Rail Traffic*, June 2010 (Lower House of Dutch Parliament, session year 2009-2010, 29 893, no. 106).

This framework memorandum states that the ALARP principle[15] is the standard applied for adequately controlling safety risks. This principle means that the responsible parties must ensure that they take the available measures unless a measure involves demonstrably unreasonable costs and/or consequences.

The Minister of Infrastructure and the Environment is responsible for the Inspectorate, which enforces the laws and regulations on the railways in the Netherlands. The Inspectorate performs enforcement in three ways: through service provision, supervision and investigation. The Inspectorate's supervisory role is particularly relevant to this investigation.

The Inspectorate issues safety certificates on behalf of the Minister to the railway undertakings, including NS. To that end the Inspectorate assesses whether a railway undertaking's safety management system functions properly. The Inspectorate similarly inspects ProRail's safety management system for the purpose of awarding the management concession. Lastly, the Inspectorate investigates accidents, incidents and irregularities. The Inspectorate enforces the law and regulations in the event it establishes failures or breaches.

European Union

The European Union draws up directives which the EU member states are required to transpose into national regulations. These directives are generally intended for a common European market, with a uniform organisation and equal opportunities for every market player. The following directives were particularly relevant to this investigation.

- Directive 2001/14/EC (administrative separation of transport operators from infrastructure managers)
- Directive 2004/49/EC (Railway Safety Directive)

Further information is given on the above directives, where appropriate.

15 As Low As Reasonably Practicable.

2 RELEVANT FACTS

2.1 Introduction

At 18:22 on the evening of Saturday, 21 April 2012, two passenger trains collided head-on leaving at least 190 people injured. A day after the accident one passenger died as a result of the injuries.[16] The collision occurred in the city centre of Amsterdam near Westerpark, between the Amsterdam Centraal and Amsterdam Sloterdijk stations. Large-scale engineering works were being carried out on the tracks between Sloterdijk and Zaandam stations that weekend, and the trains were therefore operating according to an adjusted timetable and along a reduced number of tracks.

The incident involved a sprinter and an intercity. The sprinter consisted of six single-deck coaches and was travelling from Rotterdam Centraal Station via Breukelen and Amsterdam Centraal Station to Uitgeest.[17] The intercity consisted of six double-deck coaches and was travelling from Den Helder via Amsterdam Centraal Station to Nijmegen.[18]

Arcadis has conducted an additional technical investigation into the relevant facts of the collision at Amsterdam Westerpark on behalf of the Safety Board. The report of this investigation into the facts can be downloaded from the Safety Board's website www.safetyboard.nl.

2.2 The site of the accident

The site of the collision is also known as Singelgracht Aansluiting ('Singelgracht junction') (see figure 1). This is a railway junction where trains travelling to and from Haarlem, Zaandam and Amsterdam Airport Schiphol can switch tracks before connecting with the six- track line to Amsterdam Centraal Station (see the aerial photograph in figure 2).

16 For privacy reasons, the masculine form is used to refer to all people and officers in this report.
17 Train 4058, train set 2658.
18 Train 3067, train set 8711.

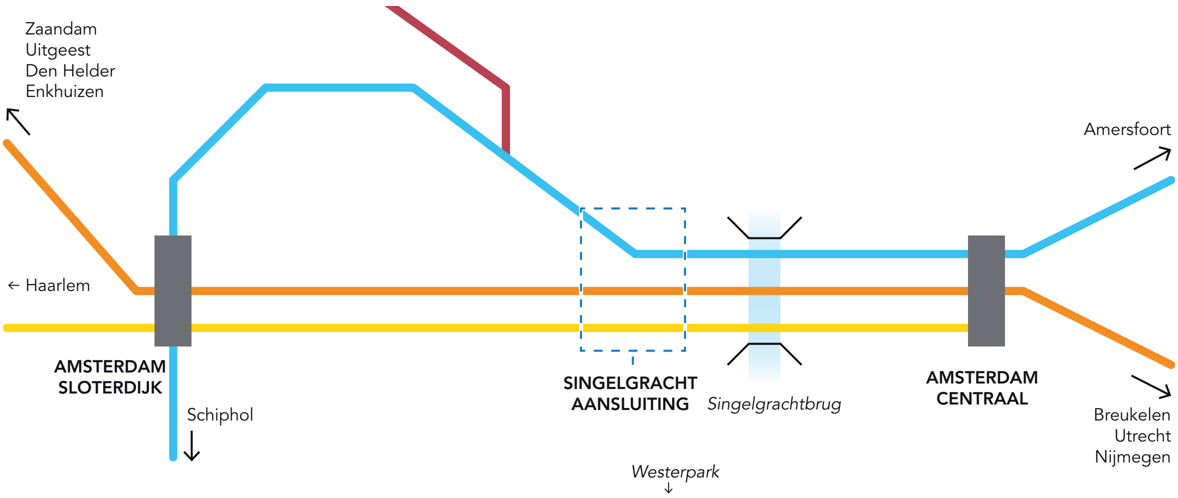


Figure 1: Diagram showing the position of the accident site. See figure 3 for a detailed diagram of the collision site.

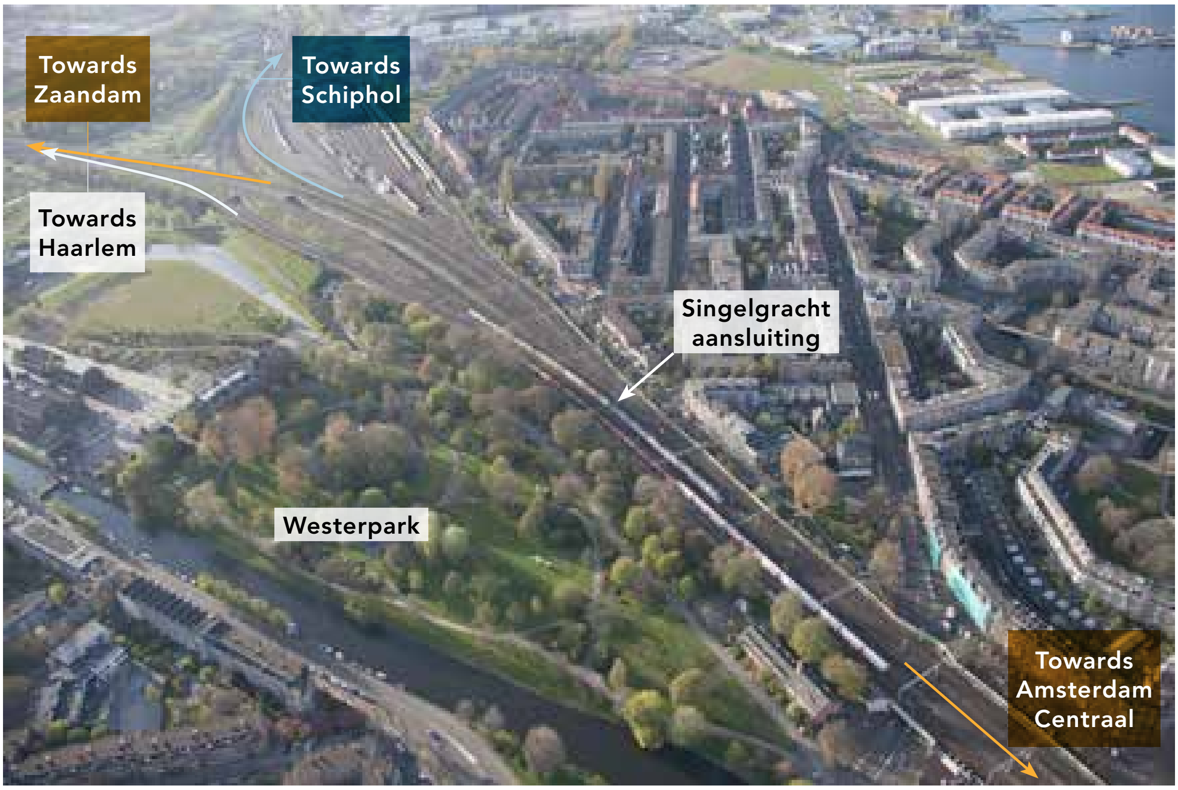


Figure 2: Aerial photograph of the accident site. Source: KLPD.

2.3 Traffic control

The signaller had started his shift in the afternoon and was operating the Singelgracht zone, which extends (approximately) from Amsterdam Sloterdijk up to and including Singelgracht Aansluiting.

The timetable had been adjusted due to engineering work on the tracks. Trains travelling in both directions between Amsterdam Sloterdijk and Singelgracht had to use one single track (single-line working).

As trains were having to wait for one another unnecessarily, the signaller consulted with his fellow signaller who was operating Amsterdam Centraal Station. They decided to direct some trains along different tracks to those specified in the timetable for the rest of the day in order to improve the flow of train traffic.

Due to the single-line working, the signaller carried out most of his work on that day manually and not, as is usually the case, using the Automatic Route Setting System (*Automatische Rijweginstelling*, ARI). He did this as he was concerned that the ARI would direct two trains along the single track in opposite directions. If this happened the trains would each encounter a red signal halfway along the track, and one of the trains would need to reverse.

The manual working approach meant that the signaller was actively focusing on the train traffic. He watched various parts of his zone in turn to see whether he could release a section of track for trains. Once a delayed goods train had passed Singelgracht Aansluiting, he could release the track for the intercity travelling from Den Helder to Nijmegen, which had to wait a short time for this goods train. After this intercity, the sprinter travelling from Rotterdam to Uitgeest via Breukelen could travel along the single track in the opposite direction. Before he could release this train movement, the signaller quickly looked at Sloterdijk station. This is because another train was travelling behind the intercity which now also required his attention.

When the signaller turned his attention back to Singelgracht Aansluiting, he saw a notification of a malfunction in a switch. He also saw that not only the intercity, but also the sprinter was located at this switch. The signaller and his team leader, who happened to be passing by, immediately thought that a collision might have happened.

2.4 The intercity

The intercity (train 3067) was being driven by a trainee train driver. He was accompanied by a mentor train driver.[19] Prior to the collision they had already driven two journeys together that day, with the last journey terminating in Den Helder. After a break they drove the intercity from Den Helder to Nijmegen.

The intercity reached track 4 at Amsterdam Sloterdijk at 18:11. This was not the usual track, due to the engineering works between Amsterdam Sloterdijk station and Zaandam station. The train's timetable had been adjusted as a result of these works. At 18:18 hours the intercity departed for Amsterdam Centraal station in accordance with the adjusted timetable. On the approach to Singelgracht Aansluiting the train driver saw a yellow signal (signal 1302). This yellow signal announces that the next signal is currently red. According to his instructions, the train driver had to reduce speed after passing this signal and prepare to stop before the next signal. When the train reached this next signal (signal 454) before Amsterdam Singelgracht Aansluiting, it was indeed red. The train driver brought the intercity to a stop in front of the red signal (see figure 3).

19 Both train drivers are fully qualified.

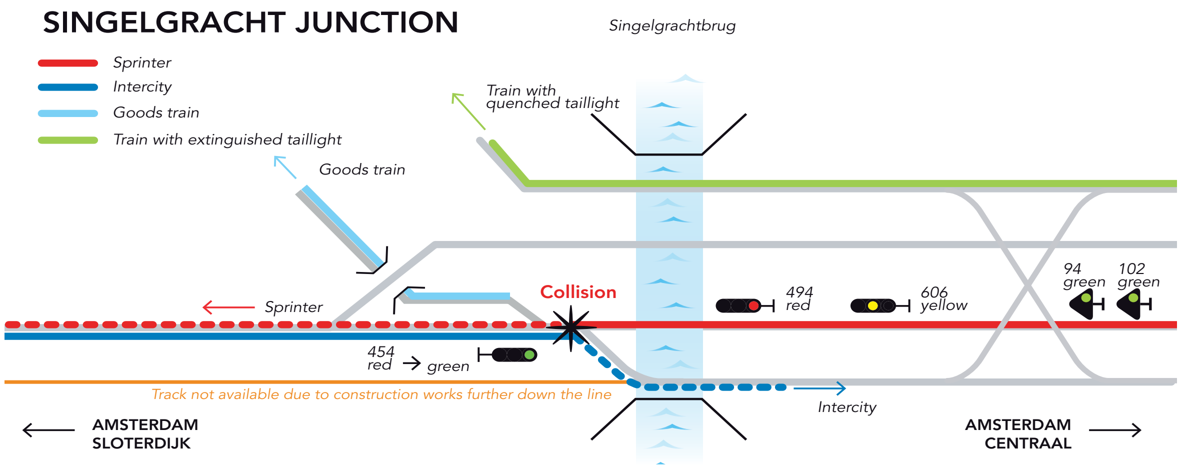


Figure 3: Diagram showing the trains running around the time of the accident. For the sake of clarity the position of the tracks is indicative and not all tracks, signals and switches are shown.

The train driver saw a goods train drive past. Once this train had cleared the switches, signal 454 turned green for his train. At this location this means that a speed of 80 km/ hour is permitted. The automatic train control in the driver's cab also indicated a maximum speed of 80 km/hour. The train driver set the intercity in motion. The train driver accelerated to just over 50 km/hour, as shortly after the signal the speed must be reduced from 80 km/hour to 60 km/hour.

At that point the signalling in the driver's cab changed: the signal no longer displayed a speed limit of 80 km/hour but returned to yellow.[20] This meant that the train driver had to prepare to bring the train to a halt (again). It is normal for the cab signal to revert in this way when the train has just passed a yellow signal, however that was not the case here. If the signal reverts under any other circumstances, this indicates a potentially dangerous situation. The tracks released for the train may no longer be safe. In this case this was due to the fact that the sprinter, with which the intercity soon after collided, was by this point travelling along a section of track along which the intercity would also travel.

The trainee train driver saw that the sprinter had travelled over the Singelgracht bridge towards the track for which the intercity was headed. He immediately engaged the brakes. The mentor train driver reacted at the same time and pulled the same brake handle. They both applied the emergency brakes. One of them also activated the danger signal (two red lights and a yellow light) to warn the approaching train. Both then attempted to evacuate the driver's cab, however they failed to do so in time.

20 The trainee train driver declared that the cab signal returned to yellow-6 (60 km/hour). The train's Train Event Recorder shows that the cab signal did not display this message, but returned to yellow. This happened a few seconds before the train passed the sign that announced the speed reduction to 60 km/hour . The train driver hears the same gong-stroke in both cases.

2.5 The sprinter

The driver[21] of the sprinter started his shift at 16:35 hours. The train driver first drove a train from Enkhuizen to Amsterdam Centraal station. After a 25-minute break the driver transferred to the sprinter (train 4058). This train's timetable had also been adjusted due to engineering works past Amsterdam Sloterdijk station. Shortly before departure the train driver and the conductor discussed a scheduled one-minute stop at Singelgracht Aansluiting that had been included in the adjusted timetable.

At the scheduled departure time the driver was granted permission to depart: signal 102 along track 7a turned green and signal 94 slightly further along the platform turned yellow in the first instance (see figure 3). The sprinter departed from track 7a towards Singelgracht Aansluiting at 18:20 hours in accordance with the adjusted timetable. As the train was driving away, the driver saw signal 94 turn green: this means that the driver no longer needs to prepare to stop at the next signal, and can drive at 40 km/hour. The driver accelerated the train to around 35 km/hour.[22]

After the switches on the west side of Amsterdam Centraal station the train reached a sign indicating a higher speed limit of 60 km/hour. In accordance with this, a gong-stroke of the automatic train protection system ATB sounded in the driver's compartment and the cab signal changed to 'yellow 6'. The driver increased the train's speed from 35 km/ hour to 43 km/hour. After 170 metres, just before the viaduct approaching the Singelgracht bridge, the train reached signal 606 (see figure 4), which was yellow (slow down to 40 km/hour and prepare to stop before the next signal). The ATB cab signal also returned to yellow. The driver allowed the speed to fall slightly from 43 km/hour to 40 km/hour.

Figure 4: Signal 606 is the middle of five signals in a row and is positioned just after leaving Amsterdam Centraal station. The photograph was taken the day after the collision. Source: Dutch Safety Board

From the departure from Amsterdam Centraal station and during the journey to the Singelgracht bridge, another train attracted the driver's attention. This train was two tracks to the right and around 280 metres ahead of the sprinter.

21 The Sprinter driver is fully qualified and has more than 10 years' experience as a train driver. He is familiar with the route section from Amsterdam to Uitgeest.
22 This can be determined from the train's Train Event Recorder.

The driver thought he saw that this train was driving with only one red rear signal light instead of two as prescribed. The driver was not able to see this properly and continued to look at the train.

The driver approached signal 494 at Singelgracht Aansluiting in this manner. This signal is positioned just before the Singelgracht bridge (see figure 5). This signal marked the end of the route that the signaller had set for the sprinter. The signal was therefore red on approach. The ATB signal in the train's cab had remained 'yellow' since the previous signal, which in this situation means that the train was approaching a red signal.[23] The ATB also monitored that the train was not approaching the signal faster than 40 km/hour.

Figure 5: Signal 494 is the fourth signal from the left and is positioned just before the Singelgracht bridge. The photograph was taken the day after the collision; the sprinter had been towed away by this time. Source: Dutch Safety Board

The train driver declared that he had seen that signal 494 before the Singelgracht bridge was yellow. The driver had expected to see a red signal according to the adjusted timetable, and was surprised to find that the signal was yellow. The driver deduced from this that the stop that appeared on the timetable print-out[24], and that had also been announced by the previous yellow signal 606, was no longer necessary at this location.[25]

As the train driver believed that he no longer needed to stop before signal 494, he decided to report the fault concerning the rear signal light of the other train. The driver pressed the 'group call' button on the GSM-R telephone system installed in the train approximately 350 metres (31 seconds) before signal 494. By doing so, the driver started a group call with all trains in the immediate vicinity.

23 The last signal passed provides information about the next signal. For example, every red signal is preceded by an yellow signal. The ATB turns yellow in the cabin as soon as the train passes an yellow signal and remains yellow, provided there is no change in circumstances, until the next signal. This is why the ATB shows yellow on approaching a red signal. If the train had been allowed to drive through signal 494, the previous signal would have been green. The cab signal would then have displayed the local speed limit of 80 km/hour.

24 A timetable print-out is a table showing the times at which a train must arrive at and depart from stations according to the timetable. It also shows midpoints along the route (such as Singelgracht Aansluiting). The train driver uses this chart to check whether he is on schedule. The chart does not show signals and tracks. The stop had been included on the timetable print-out because according to the timetable, the sprinter had to let a second intercity pass. Traffic control had changed this during the day, and this scheduled stop was therefore in principle no longer needed. The fact that the stop appeared on the timetable print-out was due to the previously scheduled (and now no longer applicable) situation. The sprinter now saw a red signal due to the handling of the goods train. The fact that the same signal showed red for this purpose at the same time as featured on the timetable print-out was coincidental.

25 The indicated signal is the guiding principle in this situation.

Operating the GSM-R system during a group call requires more attention on the part of the train driver than a normal call, as the driver must carry out more operational actions when he wants to speak. Two drivers of nearby trains responded to the call. The train driver did not answer the calls from these drivers as he wanted to keep his attention on the signals.

The driver drove past signal 494 and across the Singelgracht bridge. He was later still under the impression that the signal he had passed was yellow. Approximately 300 metres after the train had passed the signal, the sprinter drove onto the same track on which the intercity was approaching from the opposite direction. At this point the sprinter also received the signal for the speed limit that applied to the intercity.[26] This meant that the ATB cab signal changed shortly before the collision from 'yellow' (prepare to stop) to 'speed limit 60 km/hour'.

The sprinter's driver did not know at this time that he was driving on the same track as the intercity. He deduced from the cab signal that the signals now permitted a higher speed, and he therefore no longer needed to prepare to stop. The driver accelerated slightly and looked again at the rear signal of the train that was driving in front of him to the right. The driver now established with certainty that only one light of the rear signal was illuminated.

When the driver turned his gaze forward again, he saw the intercity headed straight towards him. It was issuing a danger signal: two red lights and one yellow light at the front. On seeing this, the driver immediately applied the emergency brakes.[27] This was shortly followed by a head-on collision.

2.6 Consequences of the collision

The collision took place at a gentle curve in the track. Both drivers braked heavily before the collision. Just before the brakes were engaged, the intercity was travelling at around 53 km/hour and the sprinter at 43 km/hour. At the time the trains collided, the intercity was still travelling at around 25 to 30 km/hour and the sprinter at around 20 km/hour.

2.6.1 Trains involved

Intercity
The intercity is a double decker with six VIRM-2 coaches (*Verlengd Interregio Materieel,* [Extended Interregional Stock], see figure 6). The intercity has a length of 162 metres, an unladen weight of 346,000 kg, 704 seats and 276 standing places.

26 Trains with ATB receive the speed limit from the track along which they are travelling via an antenna, and display this speed as a cab signal.

27 The sprinter rode over another railroad switch after the rapid-acting brakes had been applied. This switch was in the 'branch off' position, so that the intercity could leave the single-track section and return to its usual track. The switch was now forced by the sprinter into the 'straight through' position (which is known as running through a switch). This caused the switch to move out of its locked 'branch off' position. The sprinter's cab signalling system responded to this with a gong-stroke and by turning yellow again.

This type of train was brought into use in the period 2003-2005 and is an adapted and extended version of the DD-IRM, a type that was brought into use in the mid-1990s. NS has 178 VIRM trains in total (around 27 percent of the total number of train sets that NS has in use). The original VIRM trains were designed and built by NS and Talbot. Later series were built by Bombardier after it took over Talbot.

Figure 6: Top: external appearance of the intercity. Bottom: interior (lower deck) of this type of intercity. Source: Dutch Safety Board

The intercity is designed to transport passengers comfortably over medium and long distances. On the upper deck of the intercity the seats are positioned across from one another.[28] On the lower deck the seats are largely positioned behind one another in rows of two.[29]

Sprinter

The sprinter, type SLT (Sprinter LightTrain, see figure 7), consists of six coaches. This type of train is built by a consortium of Bombardier and Siemens and was brought into use in the period 2009-2012. The sprinter has a length of 100 metres, an unladen weight of 176,000 kg, 322 seats and 288 standing places. This type of train was developed by the consortium for NS. NS has 131 SLT sprinter trains in total (around 20 percent of the total number of train sets that NS currently has in use).

Figure 7: Top: external appearance of the sprinter; Bottom: example of the open interior of the sprinter. Source: Dutch Safety Board

28 Seats that are positioned across from one another are also referred to as 'vis-à-vis' or 'bay' seating in the literature.
29 Seats positioned behind one another in rows of two are also referred to as 'coach' seating in the literature.

The sprinter is designed to transport a large number of passengers over shorter distances. The train is mainly used on busy routes in the Randstad region. To make it easy for people to get on and off there are a large number of wide doors, wide vestibules[30] and the entrance is level with the platform. For the purpose of social safety there is a transparent interior, the main features of which are the many open vestibules and the uninterrupted view through the train due to the absence of doors between the coaches. Some seats are positioned across from one another, while others are positioned behind one another in rows of two. There is an open space in the middle of two of the coaches, in which folding seats are positioned with their backs against the side wall. These open spaces with mainly standing spaces make it possible to carry more passengers at busy times.

2.6.2 Damage to the trains

Figure 8: The trains after the collision. Source: Dutch Safety Board

Intercity

The intercity's driver's compartment was deformed during the collision. This caused the driver's desk to be moved back around 0.5 metres and pushed over the driver's seat. An air-conditioning unit mounted on the driver's desk was moved backwards along with the desk (see figure 9).

30 The vestibule is the part of the train where passengers embark and disembark.

Figure 9: Upper left: damaged nose of the intercity. Upper right: the air conditioning unit that had been pushed backwards. Bottom: damage to the driver's desk. Source: Dutch Safety Board

During the collision the coupler at the end of the train was pushed inwards around 0.3 metres. The couplers between the coaches failed, causing the coaches to collide with one another. This led to deformation of the front ends of the coaches. The coaches were also deformed at the junction between the vestibule and the passenger compartment.

Damage to the interior mainly affected the seats and the dislodging of components such as ceiling units and light boxes.

Figure 10: Top: damaged ends of coaches. Bottom left: deformed seat. Bottom right: damaged seat. Source: Dutch Safety Board

Sprinter
The sprinter's driver's compartment was not visibly deformed during the collision, however the plastic plating of the nose was destroyed. Crash absorbers are installed under this nose. These are components that are designed to absorb part of the energy during a collision. The crash absorbers under the front windshield were bent upwards (see figure 11a). The crash absorbers next to the coupler were bent sideways. The coupler itself was pushed inwards around 1.3 metres.

The couplings between the coaches are also fitted with crash absorbers. The crash absorbers between the first four coaches were compressed as far as they would go during the collision. The crash absorbers between the remaining coaches were not or only partially compressed.

Figure 11a: Top left damaged driver's compartment of the sprinter. Top right: damaged nose of the sprinter. Bottom left: nose of the sprinter following removal of the entire plastic nose. Source: Dutch Safety Board

The sprinter´s passenger compartments were not visibly deformed, however a number of interior glass partition walls were broken. A number of the bars to which these partition walls were attached had broken away from their ceiling fastenings. Some of the handrails, head rests and rear seat panels were also deformed (see figure 11b). A number of ceiling units were also partially dislodged.

Figure 11b: Top left: broken track fastening. Top Right: deformed handrail. Bottom left: glass wall. Bottom right: deformed seats. Source: Dutch Safety Board

2.6.3 Injuries among occupants

Based on data from NS and the Dutch National Police Services Agency (KLPD), the number of train occupants has been estimated at a total of 425 (3 train drivers, 2 chief conductors and 420 passengers[31, 32]).

The Safety Board collected information about the injuries sustained by the train occupants, who themselves described the injuries they had suffered and how they occurred. The Safety Board received information from 247 people in the passenger sections (passengers and conductors) and from the three train drivers: 250 occupants in total.33 Information about the nature of the injuries and their location on the body can provide an insight into how these injuries occurred.

The occupants described the following injuries:

- Head and neck: a bump on the head, mild concussion, and more drastic injuries such as a broken spine or concussion leading to temporary loss of consciousness.
- Face: a bloody nose, a tooth through the lip, a graze to the face, and a broken nose or dislocated jaw.
- Chest: bruising to the back, a contusion to the chest and a bruised rib or sternum, or broken ribs and a fractured sternum.
- Abdomen: bruising to the abdomen or damaged organs such as the liver.
- Arms and legs: bruising to the arm and a graze or contusion to the elbow to a broken ankle, a broken kneecap and an open fracture of the lower leg.

The reported injuries were classified according to the standardised injury scales used for the purpose of investigation and research into injuries suffered during transport accidents.[34] For the purpose of this investigation, a distinction was made between minor and serious injuries. Minor injuries include injuries that heal quickly and do not affect or have a limited effect on the lives of the individuals involved, such as bruising, bleeding noses or grazes.[35] Serious injuries include injuries requiring treatment, such as fractures and internal bleeding.[36] Table 1 provides an overview of the severity of the injuries sustained in each train. This table shows that a large number of occupants of both trains sustained injuries, most of which were minor.

- 93 of the 128 intercity occupants known to the Safety Board reported injuries. The investigation revealed that nine of these people suffered serious injuries.
- 96 of the 121 sprinter occupants known to the Safety Board reported injuries. The investigation revealed that fourteen of these people suffered serious injuries.

31 The Safety Board does not have any information on the exact number of occupants due to the fact that no records are kept of the number of occupants in trains.

32 The 420 passengers included another two NS staff members who were travelling on one of the trains in their free time.

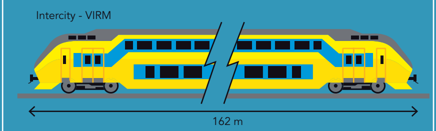
33 For more detailed information see Appendix 1 'Explanation of the investigation'.

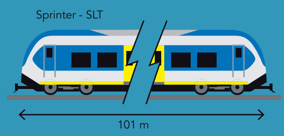
34 Appendix 7 provides information on the injury scales used for this investigation. These global standardised injury scales, i.e. the Abbreviated Injury Scale (AIS) and the Injury Severity Score (ISS), are used in the field of traumatology.

35 In injury scales: AIS 1 and ISS 1-3.

36 In injury scales: AIS $\geq$ 2 and ISS $\geq$ 4.

It is not possible to calculate the percentage of occupants injured, as neither the total number of injured people nor the total number of people in the trains are known. Based on the highest estimate of the number of occupants (425), however, as many as around half of all occupants sustained injuries.





		Intercity - VIRM				Sprinter - SLT			
	Total	No injury	Minor	Serious	Died	No injury	Minor	Serious	Died
Train drivers	3	0	1	1	0	0	1	0	0
Passengers	247[37]	35	82	8	1	25	81	14	0
Total	**250**	**35**	**83**	**9**	**1**	**25**	**82**	**14**	**0**

Table 1: Overview of injuries in both trains (if known by Dutch Saftey Board).

The injuries reported by the occupants show that a large number of occupants sustained more than one injury.[38]

- Most injuries reported concerned the limbs and the face, followed by the chest region and the head.
- Occupants of the sprinter reported a large number of and more serious injuries than those of the intercity, particularly to the head and in the chest region.
- Neck injuries were reported in both trains.
- The sprinter's driver sustained a minor abdominal injury. Abdominal injuries were only reported by passengers in the intercity. Three injuries were reported, two of which were serious. One of the intercity's occupants died a day later.

37 It is not known on which train one seriously injured person was travelling.
38 Appendix 8 provides an overview of the reported injuries.

3 THE CAUSES OF THE COLLISION

This Chapter has not been translated. The main findings are included in the summary and the conclusion chapter of this report.

4 INJURY RISK MANAGEMENT

4.1 Introduction

Train passengers expect to arrive safely at their destination. As transport concession holder on the main railway network, NS bears a duty of care for safety, ensuring: '... *[that] an adequate level of safety can be guaranteed for both passengers and employees in the trains and stations*'.[39] The Dutch Safety Board expects the concession holder to implement an overall safety policy, which also addresses the consequences of emergencies such as collisions.

In view of this requirement, the Safety Board decided to examine the aspect of train crashworthiness in its investigation into the train collision on 21 April 2012, firstly because this crash claimed a large number of victims and secondly because no specific investigations had as yet been carried out into crashworthiness by either the Dutch Safety Board itself or any other investigating authority.[40] The Safety Board has looked in particular at what the parties involved have done to minimise the risk of injury to occupants as the result of a collision.

This chapter first discusses injury risk management in the event of collisions in general: the factors relevant to the occurrence of injuries and the measures available to help limit injury risk. The chapter then describes the underlying causes of the injuries sustained during the collision on 21 April. The injuries are related to the characteristics of the collision and the trains, in order to gain insight into the factors contributing to the injuries and the factors that helped limit the injuries.

4.2 Injury risk management in the event of a train collision

A train collision involves various phases. In the first phase, the primary collision, a train collides with another train, vehicle, or object on the railway track. During the second phase, the secondary collision, occupants collide with the train interior, with other occupants and/or with objects. The forces exerted on the body during this secondary collision determine whether or not injuries will occur and – if so – how serious they will be.[41] These forces depend on the occupant's mass and acceleration. The greater the mass and acceleration, the greater the force.[42]

39 Source: Transportation Act 2000 and Transport concession for the main railway network 2005-2015, Chapter II, Article 6.

40 For instance the Environmental and Transport Inspectorate or NS.

41 These forces can both 'directly' (in the form of broken bones and contusions) and 'indirectly' cause injuries (due to organs colliding within the body, also known as tertiary collisions, which can in turn result in internal haemorrhaging and disruption of the circulation). Occupants may also become injured as a result of the rebound effect that can occur following a secondary collision (for example the whiplash effect).

42 Acceleration is the rate at which the occupant's velocity changes per time unit. Negative acceleration, in other words a reduction in velocity per time unit, is also referred to as deceleration.

Various factors influence the occurrence of injuries during both the primary and secondary collision. In view of these factors, specific measures can be taken in relation to the structure of the train and its interior in order to limit the injury risk.

4.2.1 Factors relevant to the occurrence of injuries during a collision

During the primary collision, the train and the other vehicle or object involved in the collision will exert forces on one other. As a result, the train's speed will be reduced (1), the train's structure will deform (2) and the train may be derailed (3). The greater the force, the greater the change in the train's velocity per time unit will be (the acceleration). The greater the force, the more the train will be deformed and the greater the likelihood of a derailment.

Change of velocity (1)
The train's velocity will change abruptly during a collision. Before the collision an occupant will have the same speed as the train. However, the abrupt change of velocity occurring during a collision will create a difference in velocity between the train and the occupant. If a train brakes abruptly, the occupant will basically continue to travel at the same speed in the direction in which the train is heading. This means that an occupant seated facing the direction of travel will be ejected from his seat. Occupants seated with their backs towards the direction of travel will be pushed deeper into their seats. Occupants also experience this effect when a train brakes abruptly.[43] When occupants move through the train as a result of the change of velocity, they may collide with the interior, other occupants, or objects in the train (such as baggage items). Occupants can also be ejected from the train, however this is less likely. These events can cause the occupants to sustain injuries. If the acceleration is great enough, injuries may also occur spontaneously as organs and limbs exert excessive forces on one another.[44]

Deformation (2)
A collision will cause the train's structure to deform. This deformation can extend to the train driver's compartment or the passenger compartments. As a result, the space in which the train driver or passengers are seated will be compressed placing the occupants at risk of becoming crushed, resulting in injuries.

Derailment (3)
A collision may also cause a train to derail. This derailment can then lead to another collision if the derailed train ends up on the adjacent railway track and collides with a train travelling over this track.

43 During normal service, acceleration is limited by the traction and brake system and is low compared to acceleration that occurs during collisions.
44 Shanahan, D.F., 2004, Human Tolerance and Crash Survivability. NATO/OTAN, RTO-EN-HFM-113.

During the secondary collision, the occupant and the part of the train's interior or person with whom he or she collides will exert forces on one another. The nature and seriousness of the injuries will depend on the magnitude of these forces (1), the obstacle with which the occupant collides (2), the part of the body which strikes the obstacle (3) and the occupant's posture at the time of the collision (4). These four aspects will be explained in further detail below.

Force of the secondary collision (1)
A number of factors determine the force that an occupant and the interior (or another occupant) exert on one another during a collision. They include the weight of the occupant, the difference in velocity between the occupant and the train, and the characteristics of the obstacle (2). The greater the weight and the difference in velocity, the greater the force. The difference in velocity depends on the occupant's distance to the obstacle with which he collides and the speed development of the train during the collision. Up to a certain distance, the greater the distance, the greater the difference in velocity. Beyond this distance the speed difference stabilises. The greater the distance, the longer it takes for the collision to occur and the train's velocity can decrease further compared to the occupant's velocity in this time. Occupants in vestibules, open compartments and seats facing one another can travel a greater distance than occupants in seats that are positioned behind one another. They can therefore collide against obstacles or each other at greater speed.

Obstacle characteristics (2)
The dimensions of an obstacle will determine how much of the body's surface is involved in the collision. The smaller this surface area the greater the risk of injury, for instance if a table edge has a thinner design. The extent to which the obstacle yields during collision with an occupant will also affect the nature and seriousness of the injuries.

Place of impact on the body (3)
The likelihood and seriousness of injuries will depend on which part of the body is impacted. For example, the abdominal cavity is more vulnerable than an arm or leg. If vulnerable tissue is affected there is also a higher risk of serious injury.

Posture (4)
The occupant's posture in the train also influences the likelihood of injury. To a large extent, the occupant's posture is determined by the characteristics of the seat or standing place: are the seats positioned across from, behind one another, or sideways alongside each other? These characteristics determine how the occupants will move through the space during a collision and the manner in which they will collide with the train interior.[45] The individual's seating posture also plays a role: for example, was the occupant sitting with his legs crossed, leaning to one side or slumped in his seat at the time of impact?

45 How an occupant moves through a space in the event of a collision (horizontally, vertically or sideways) is also determined by the train's movement.

4.2.2 Measures to minimize injury

The likelihood of injury during a collision can be reduced by taking a number of measures. These measures relate to both the train's structure and its interior.

Measures on the train's structure

Measures on the train's structure can influence various characteristics of the train:

- how much and how quickly the velocity changes during a collision
- whether and how the structure is deformed
- the likelihood that the train will derail.

The change of velocity experienced by trains involved in a collision is determined by the speeds, the mass of the vehicles/objects involved in the collision and the extent to which the deformation is permanent. Fitting the train with energy absorbers will help extend the period of time during which the change of velocity takes place during a collision. This can consist of special crash absorbers, but also crumple zones. These are zones integrated into the train's structure that are designed to deform in the event of a collision.

Crumple zones help ensure that the train does not deform uncontrollably in the event of a collision. They are parts that are designed to be weaker than the rest of the train structure, and which therefore prevent the rest of the structure from becoming deformed during a collision.[46] The installation of crumple zones and strengthening of the driver's compartment and passenger compartments will help ensure that the train does not deform uncontrollably in the event of a collision. This will help reduce the likelihood of occupants becoming trapped.

A number of measures can be taken to minimize the risk of derailment. Trains derail as a result of becoming separated from the track during a collision, for instance if the train drives over an object. The use of an item known as an obstacle deflector reduces this risk. Derailment can also occur when coaches ride up over one another in the event of a train-on-train collision. Anti-climb systems have been developed to reduce this risk.

Measures on the train's interior

A number of general measures can be taken on the train's interior to reduce the risk of injury.[47] They include minimising the distance between passengers and any objects with which they could collide (1), fitting the interior with collision-friendly features (2), ensuring there are no loose objects that could fly around the compartment (3) and installing safety systems (4). The section below provides examples of measures in each of these areas.

Limiting the distance to the obstacle (1)

There are a number of ways of limiting the distance to an obstacle. They include seats placed behind one another facing away from the direction of travel, partition walls in open passenger compartments, staggered aisles in the compartments or installing specially designed tables over the entire width between seats that are positioned facing one another.

46 Also referred to as the crumple zone/safety cage principle.
47 Also see the outcomes of European Safeinteriors, 2010. Train Interior Passive Safety for Europe – Publishable Final Activity Report. Specific Target Research Project (STREP). FP6-031-260.

Collision-friendly features (2)
A collision-friendly interior also prevents injuries. Collision-friendly features include seats, tables and partition walls that are designed to yield during a collision, thus limiting the force exerted on occupants. Collision-friendliness can also be improved by rounding off the corners of interior components and increasing their surface area, such as the thickness of a tabletop or the diameter of handrails. Interior components can also be made foldable, particularly those at risk of being impacted by vulnerable body tissue in the event of a collision.

Preventing objects from flying around the compartment (3)
Another way of preventing injury is to ensure there are no loose objects that could fly around the compartment in the event of a collision. This is achieved by fastening interior components securely to prevent them from becoming dislodged during a collision and by installing facilities to help secure baggage items.

Installation of safety systems (4)
Finally, there are a number of systems that can improve safety. They include seatbelts, airbags and other safety-oriented interior modifications that will help limit the forces exerted on occupants in the event of a collision. For example, seatbelts will ensure that occupants remain in their seats during a collision, and therefore cannot collide with the interior or with other passengers. If they do collide, airbags help to cushion the blow. To ensure optimal effectiveness, safety systems must be aligned with the rest of the interior and the characteristics of the occupants. They must also be used as intended, and regularly maintained and inspected.

4.2.3 Laws and regulations
The protocol for managing injury risks in the event of a collision is embedded in laws and regulations.[48] New passenger trains are not admitted to the Dutch railway network until the owner/operator has demonstrated that the train complies with these laws and regulations.[49] This specifically concerns the requirements set out in the Railroad Vehicle Commissioning Regulation (*Regeling indienststelling spoorvoertuigen*, RIS) and European regulations.[50] These regulations also specify requirements as to the train's crashworthiness. These requirements are summarised below.

Crashworthiness of the train structure
Under the current requirements, the owner/operator must demonstrate that the train is designed to be resistant to the following four collision scenarios:

48 For more information on this subject see Appendix 4.
49 The train is then granted a permit and can be brought into service.
50 Regulations regarding the collision safety of passenger trains mainly concern the TSI on Locomotives and Passenger Rolling Stock, EN standards 12663 (structural requirements) and 15227 (crashworthiness) and UIC leaflets 566 (loadings of coach bodies and their components) and 564 (safety glass).

1. collision with an identical train at a speed of 36 km/hour
2. collision with an 80-ton wagon equipped with side buffers at a speed of 36 km/hour
3. collision with a 15-ton obstacle (truck model) at a speed of 90 km/hour[51]
4. a 300/250 kN longitudinal force exerted on the obstacle deflector (at 0 and 75 cm from the centre, respectively).

As regards scenarios 1 to 3, the passenger compartments and vestibules may only be subjected to a certain degree of deformation. At the same time, the amount of space in the driver's compartment must meet certain minimum requirements in order to ensure that the train driver survives the impact. The average acceleration of the driver's and passenger compartments may not exceed 5 g during scenarios 1 and 2 and 7½ g during scenario 3, for the entire duration of the impact.[52] Moreover, in a scenario where trains collide with a height difference of 40 mm the trains must not ride up over one another, and at least one wheel set of every bogie shall be maintained in effective contact with the track. This reduces the risk of derailment.

Crashworthiness of the train's interior
There are no detailed legal requirements with regard to the crashworthiness of the train's interior. A number of specific aspects are described in the relevant UIC (*Union Internationale de Chemins de Fer*[53]) leaflets. They include the fastening of objects, fire resistance and the safety characteristics of glass applied in the structure. According to the Technical Specifications for Interoperability (TSI), European research is currently being carried out to determine the admission requirements or assessment procedures for the design of train interiors. The ERA is following this research and will advise the European Commission regarding the amendment of the regulations.

4.3 The primary collision and its effects on the occurrence of injuries

This section describes the effects of speed development, deformation and derailment on the occurrence of injuries during the collision on 21 April.

4.3.1 Train speed development and its effects on the occurrence of injuries

The intercity approached the site of the accident at around 54 km per hour. The sprinter approached at around 43 km per hour.[54] With both train drivers having heavily engaged the brakes, the intercity was still travelling at around 28 km/hour and the sprinter at around 20 km/hour.[55] A computer calculation was conducted to gain insight into the development of the two trains' coach speeds during the collision.[56]

51 In the Netherlands, level crossings are only found on route sections with a maximum speed of 140 km/hour and the collision test speed in this country is therefore 140-50 = 90 km/hour (instead of 110 km/hour).
52 The abbreviation g stands for gravitational acceleration, and equates to a rate of change in velocity of 9.81 m/s² (35 kilometres per hour per second).
53 Also referred to as the International Union of Railways. This international union strives to promote railway transport around the world and to combine mobility with sustainability. To this end, the union gathers best practices which it bundles in standards for the sector, referred to as UIC leaflets. Also see http://www.uic.org/.
54 According to both trains' Train Event Recorder (TER).
55 Analysis of the TER data showed that the intercity collided at a speed of 22-34 km/hour while the sprinter collided at a speed of 16-24 km/hour. The analysis of the TER data is explained in further detail in Appendix 9.
56 The report is available as a digital appendix to this report on the website www.safetyboard.nl

Figure 13 shows the calculated speed development of various coaches in the two trains. The calculated speed development provides an indication of the actual course of events. The first coaches of both trains are the front coaches that collided with one another during the collision.

According to the indicative calculation, the intercity continued to travel forward at a speed of approximately 10 km/hour after the collision. The sprinter was no longer travelling forward at this time, and was moving backwards at a speed of approximately 16 km/hour. The collision therefore caused a change in the sprinter's speed that was approximately twice as great as that of the intercity: around 36 km/hour and 18 km/hour respectively. This difference is attributable to the fact that the intercity is approximately twice as heavy as the sprinter. Based on this change in speed, it would appear that the sprinter's passengers were at greater risk of injury than those travelling in the intercity.

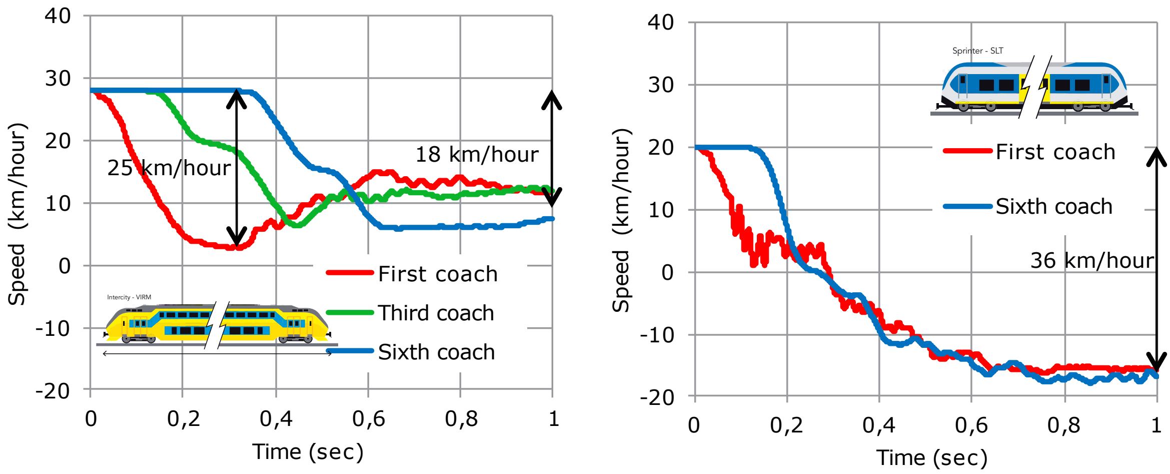


Figure 13: The speed development of various coaches in the two trains during the collision.

However, the speed of a secondary collision may be greater than the change of velocity of the train as a whole due to the collision. This is because the various coaches will change speed at a different rate during the collision due to the couplers that connect them. As the couplers between the sprinter's coaches are more rigid than those on the intercity and the distance between the coaches is smaller, the sprinter behaved more as a rigid whole at the start of the collision, while the first coach of the intercity behaved more as a separate coach. This means that the first coach of the intercity underwent a 25 km/hour change of velocity during the collision, while the intercity as a whole ultimately experienced an 18 km/hour change of velocity. Section 4.4.1 will focus on this issue in greater detail.

Incidentally, major changes of velocity per time unit (accelerations) can result in spontaneous injuries. Based on the calculated accelerations, it is unlikely that this occurred during the collision on 21 April.

Section 4.2.2 describes how the duration of a collision will be extended if the train has been fitted with energy absorbers (crash absorbers and/or crumple zones). These absorbers will reduce the train's acceleration and also reduce the collision´s impact on the occupants.

The intercity involved in the incident on 21 April was (apart from the automatic couplers[57]) not equipped with these types of energy absorbers. The deformation of the front cabin and the ends of the coaches shows that the train also absorbed energy.

The front of the sprinter had, to a greater extent than the intercity, been fitted with various energy absorption features in order to cushion the impact of a collision. These features were installed in three locations: behind the automatic coupler, next to the automatic coupler and under the front windshield. The crash absorber behind the automatic coupler absorbed part of the energy during the collision. The other crash absorbers hardly absorbed any energy. Because the structure and shape of the intercity's nose were incompatible with that of the sprinter, they were not pushed back in a straight line. Instead they were bent sideways (see figure 14, left) and upwards (see figure 14, right). The impact on the crash absorbers was different to that taken into account in the design. The crash absorbers at the front of the sprinter bent outwards, grazing the contours of the intercity's nose.

Finally, the couplers between the sprinter coaches were also fitted with crash absorbers. These absorbers functioned properly during the collision.

57 An automatic coupler is used to automatically couple trains to one another, in contrast to a screw coupler, where the trains must be coupled manually.

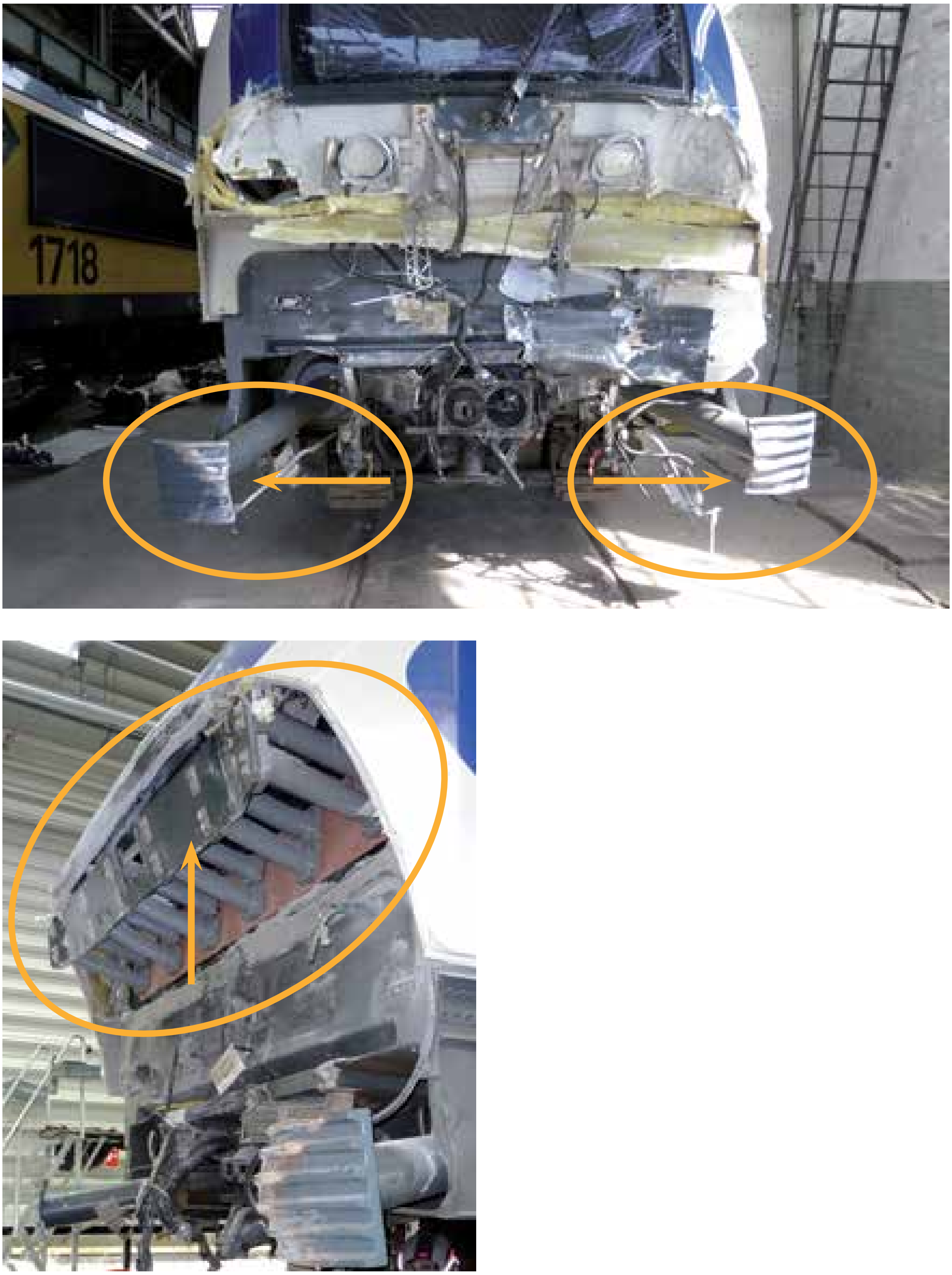


Figure 14: The two photos show the sprinter's twisted crash absorbers (lower photo: after removal of entire plastic nose). Source: Dutch Safety Board

4.3.2 Deformation and its effect on the occurrence of injuries

As the investigation showed, the deformations in various parts of the train also affected the train interiors. The deformations and their effects on the driver's and passenger compartments varied.

Intercity driver´s compartment

The investigation revealed that the front of the intercity was especially deformed by the impact of collision. This deformation of the train's structure also affected the driver's compartment interior: the driver's desk and the various interior components connected with it were pushed back around 0.5 metres, thus reducing the amount of survival space available to the train driver and second man (see figure 15). The train driver and second man thus ran the risk of becoming trapped and sustaining potentially fatal injuries. In accordance with the unwritten rule, the two both left their seats right before the collision. They therefore avoided becoming trapped, however they did not escape injury (see section 4.4.2).

Figure 15: Compacted intercity driver's desk. Source: Dutch Safety Board

Sprinter driver's compartment

The driver's compartment of the sprinter remained intact despite the force of the collision and the fact that the energy absorbers were only partially effective due to incompatibility with the intercity nose. All in all, the sprinter driver ran a smaller risk of becoming trapped as the driver's compartment on the sprinter was stronger. Nevertheless, this train driver also suffered injuries (see 4.4.2).

Coaches

The intercity's coaches collided with one another. This resulted in deformation of the ends of the coaches (see figure 16). These deformations were not serious enough to cause the entrapment of any occupants. However, they did affect the train interior (see section 4.4.2). The sprinter's coaches were barely deformed.

Figure 16: Deformation of the ends of the intercity coaches. Source: Dutch Safety Board

4.3.3 Derailment and its effect on the occurrence of injuries

Neither of the trains was derailed. The trains collided head-on on a section of the track that was almost entirely straight. This meant that lateral forces were limited to a minimum. Moreover, both trains had been fitted with systems to limit the risk of derailment. Although the trains did not become derailed during this collision, the investigation did show that there was a risk of derailment. The damage incurred by the trains shows that the sprinter 'rode up' against the intercity. This process could potentially have culminated in derailment.

Two occupants of the intercity's first coach were injured due to being hit in the abdominal region by the fixed tables. Occupants of the other coaches reported injuries to the chest region. One passenger in the intercity's first coach reported having hit his head on the baggage rack. Occupants of the first coach therefore reported sustaining different types of injuries to occupants of the other coaches. This could be to do with the occupants' physical stature and posture. Another possible explanation is that the occupants of the first coach were thrust upwards during the collision. This movement occurs when occupants are more inert than the train as it moves downward, or are ejected from their seats as the train makes an upwards movement. This phenomenon may have occurred during the collision on 21 April as the sprinter rode up against the intercity.

4.4 The secondary collision and its effects on the occurrence of injuries

The course of the primary collision affects the secondary collision, in other words the manner in which occupants collide with an obstacle in the train. This section relates the injuries reported by occupants to information on their location in the train, in order to gain an insight into the mechanisms that resulted in injury.[58]

58 Appendix 1, 'Explanation of the investigation', features more detailed information on the structure of the injury investigation. In supplement to the general overviews featured in section 2.6.3 and this chapter, Appendix 8, 'Injuries, causes of injury and passengers' position in the train' features a number of detailed extracts from the information obtained by the Safety Board regarding injuries that occurred during the collision.

It is not possible to carry out a detailed analysis of the relationship between the observed injuries and the characteristics of the trains involved, as no overview is available of each passenger's seating or standing place at the time of the collision and their position after the collision.

4.4.1 The speed of the secondary collision and its effects on the occurrence of injuries

The speed of the secondary collision depends on the speed development of the occupant's coach during the collision, and the occupant's distance to the obstacle with which he collides. Section 4.3.1 provides an indication of the development of the speed of the coaches during the collision. An indication of the speed of the secondary collision has been calculated on the basis of this speed development (see figure 17).

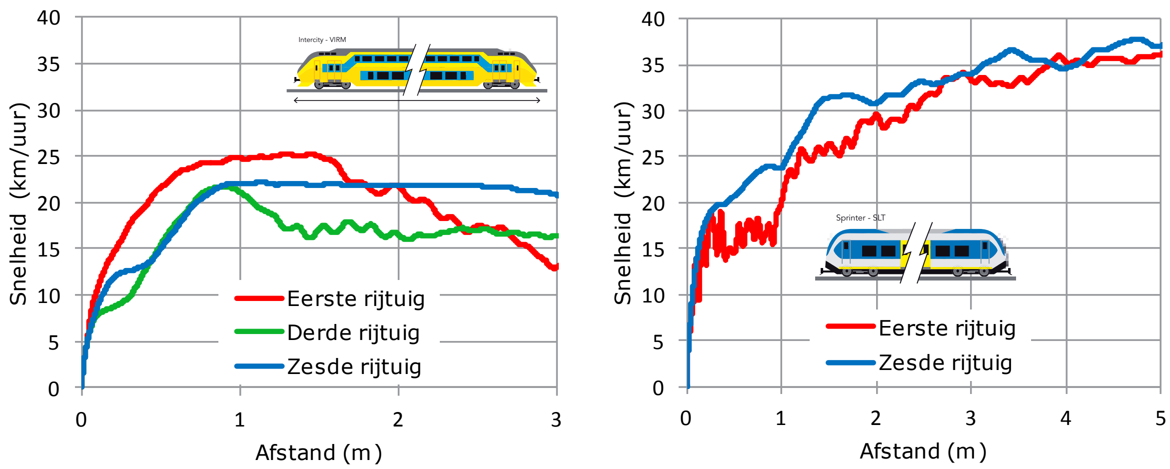


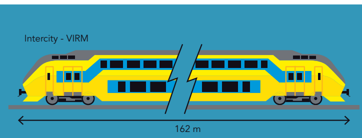
Figure 17: The speed of the secondary collision in relation to the distance between occupant and interior component.

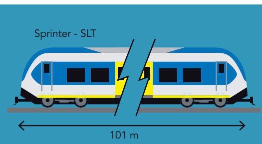
According to the indicative calculation, it was possible for occupants of both trains to collide with an obstacle at even small distances with a considerable speed. Up to a certain distance the speed in the first intercity coach, could exceed the speed in the other coaches of this train. More injuries were reported in the first intercity coach than in other coaches. The injuries were also more serious. The individual who died a day after the incident as a result of her injuries was also sitting in the first coach. This distribution of injuries corresponds with the indication of the speed of the secondary collision shown in figure 17.

According to the indicative calculation, it was possible for occupants of the sprinter to collide with an obstacle at a higher speed if they were able to travel a relatively large distance. In comparison with the intercity, the seriousness of injuries was more equally distributed over the various coaches in the sprinter. The number of injured in the front and rear coaches exceeded those in the middle coaches by several people. However, a larger number of people also stated that they were located in the front or rear at the time of the collision. There was no way of determining whether the distribution of injured passengers was related to the distribution of passengers throughout the train or the speed of the secondary collision in the various sprinter coaches.

4.4.2 Characteristics of the train interior and their effects on the occurrence of injuries

The information provided by occupants showed that a large number of occupants of both trains suffered injuries. At least 93 people on the intercity and at least 96 people on the sprinter were injured. The information provided also showed that the train interior was most frequently mentioned as the cause of injury (table 5). The second most common cause of injury mentioned by occupants was physical contact with other occupants. Sprinter occupants mentioned this particular cause of injury more frequently than intercity occupants. Only a few occupants mentioned baggage as a cause of injury. All of these cases concerned minor injuries.[59] The latter is especially noteworthy in view of the fact that 'baggage items flying around' was a key point of attention in the crash safety investigation.[60, 61] As baggage did not play a significant role in this collision, the risks involved in baggage items flying around the train have not been investigated further.





	Minor	Serious[62]	Minor	Serious
Train interior	68	9	51	10
Other occupant	13	2	33	2
Baggage	1	-	5	-
Unknown	7	-	7	3

Table 5: Relationship between cause and seriousness of injury.[63, 64]

The following factors played a role in the relationship between the injuries reported by occupants and the interior of both trains: distance between occupant and obstacle (a), characteristics of the train interior (b), objects flying around the coach (c) and specific safety systems (d).

Effects of the distance between occupant and obstacle on the occurrence of injuries (a)

Passengers can suffer injuries when they are thrust forward from their seat as a result of the collision or hit by other passengers or objects flying through the coach.

59 Minor injuries include injuries that heal quickly and do not affect or have a limited effect on the lives of the individuals involved, such as bruising, bleeding noses or grazes (injuries described by the individuals involved, classified as AIS 1 and ISS 1-3 for the purpose of this investigation). Serious injuries include injuries requiring treatment, such as fractures and internal bleeding (injuries described by the individuals involved, classified as AIS ≥ 2 and ISS ≥ 4 for the purpose of this investigation).

60 Davis Associates Ltd (DA), 2008. Management of on-train crowding. Report prepared for the Rail Safety and Standards Board Ltd (RSSB).

61 Safeinteriors, 2010. Train Interior Passive Safety for Europe – Publishable Final Activity Report. Specific Target Research Project (STREP). FP6-031-260.

62 The cause of the injury sustained by the passenger who died is included under 'serious'.

63 The table is based on the main causes specified and does not break these causes down further into components of the train's interior, the position of fellow passengers or types of baggage items. The available information was not sufficient to allow a further breakdown.

64 The sum total of the amounts specified in the table exceeds the total number of injured occupants mentioned in section 2.6.3 due to the fact that a number of occupants specified multiple causes for their injuries, such as contact with both another occupant and the train interior.

The greater the distance travelled by a passenger before he hits something or someone else, the greater the collision speed[65] and thus the likelihood of injuries. This distance depends on the characteristics of the occupant's seat or standing place at the time of the collision.[66] Both the direction in which the train is heading and the amount of available space play an important role. Based on the information provided by the occupants of both trains, it was possible to relate the seriousness of the injuries sustained to the most common seating and standing place types.[67] The injuries described correspond with the outcomes of studies into the risks of travelling in a forward and backward facing direction and the risks of open spaces:

- Passengers travelling in a backward facing direction reported fewer injuries than those travelling in a forward facing direction. The investigation showed that the injuries of those travelling backwards were generally less severe than those suffered by passengers travelling in a forward facing direction.
- Approximately three quarters of the injured passengers who were seated across from one another and were facing backward related their injuries to contact with another passenger. Passengers seated in this position also reported neck injuries as a result of uncontrolled head movements.
- Passengers seated perpendicular to the direction in which the train was heading reported a relatively large amount of injuries. This phenomenon is not explained in previous investigations into crashworthiness, as these studies focus on seated passengers travelling in a forward or backward facing position, and passengers travelling in a standing position.[68]
- A large number of the passengers travelling in the trains' open areas sustained injuries. 'Open areas' include: the vestibules of both trains, the intercity stair landings and the aisles in sprinter compartments with lateral seating. Passengers in these open spaces developed greater speed when ejected from their seats or falling from a standing position during the collision. The number of injured occupants and the seriousness of injuries were greatest in the sprinter. These trains are designed with social safety in mind and with the aim of transporting large numbers of passengers over short distances, as a result of which they have more open spaces than intercity trains. This may have played a role in this regard.

The effects of train interior characteristics on the occurrence of injuries (b)
The characteristics of the interior components with which the occupant collides will affect the occurrence of injuries (see section 4.2). The information provided by occupants themselves on injuries and their causes allowed for the formulation of points for attention regarding the characteristics of the interior components with which they collided. These points for attention extend to both the individual interior components and the materials from which they are made.

65 The speed of the secondary collision increases up to a certain distance, after which it stabilises.
66 Appendix 8, 'Injuries, causes of injury and passengers' position in the train', features an overview of the number of passengers who reported injuries, the types of seating or standing place they described and the seriousness of the injuries sustained.
67 Passengers can travel facing forwards, backwards or sideways. They can also travel either sitting down or standing up. The seats are placed behind one another, across from one another or along the walls of the train. Also see Appendix 8 'Injuries, causes of injury and passengers' position in the train'.
68 Safeinteriors, 2010. Train Interior Passive Safety for Europe – Publishable Final Activity Report. Specific Target Research Project (STREP). FP6-031-260.

The injuries in the driver's compartment have been assessed separately from those in the passenger compartments, due to the major differences between these train sections' respective functionalities and the damage they incurred.

Driver's compartments in the intercity and sprinter
The train driver and second man of the intercity did not become trapped in the driver's compartment, as they had left their seats before the collision took place. However, they were injured when they collided with the interior of the driver's compartment during their efforts to evacuate. The train driver suffered minor injuries, probably as a result of contact with the driver's desk, his chair, and broken glass from the front windshield. The second man suffered injuries to the head, neck, nose, ribs and shoulder, probably as a result of contact with the air conditioning unit and the rear wall of the driver's compartment (see figure 18). These injuries were serious enough for the second man to require hospital treatment. The investigation also identified protruding objects in various parts of the driver's compartment, such as coat hooks and foldable armrests. One of these protruding objects may have played a role in the second man's failed escape attempt.[69] It is important that the escape route is not blocked in any way, for precisely the reason that the people inside need to evacuate the compartment in the event of a collision.

69 Information from an interview.

Figure 18: Top: interior of intercity's driver's compartment, at second man's station. The photo clearly shows the retracted air conditioning unit and dented rear wall, with circles around the probable contact points. Bottom: sprinter driver's compartment interior with console. Source: Dutch Safety Board

The sprinter driver suffered injuries to the abdominal region when he was ejected forwards from his seat and collided with the driver's desk. The injuries were limited, despite the considerable speed at which the secondary collision occurred. This may have been partly due to the favourable characteristics of the driver's desk's, such as its shape – thick edge, rounded corners – and the materials from which it is made (see figure 18).

Interior of the intercity and sprinter passenger compartments

Nearly all passengers who had been travelling in the direction in which the train was heading while sitting on seats positioned behind one another in rows reported injuries due to contact with the rear of the seat in front of them. These were mainly injuries to the facial area, such as injuries to the nose (ranging from bloody noses to broken noses), but also injuries to the knees and lower legs (ranging from grazes to bruised knees). The investigation identified a clear difference between damage sustained by the rear sections of the seats on the intercity and the sprinter (see figure 19).

Various intercity seats became deformed as a result of contact with passengers. Several of the plastic rear seat coverings were cracked, and holes with sharp edges appeared in various places.

The headrests of various sprinter seats were bent forward. The aluminium plate at the rear of several chairs was dented at knee-height. The deformation of these seats helped to limit the force exerted on the occupants who collided with the seats, thus limiting the risk of injury.

Figure 19: Damage to the intercity and sprinter interiors. Top left: broken plastic in the rear of intercity seats, at head height; Top right: broken plastic in the rear of intercity seats, at knee height; Bottom left: damage to the rear of sprinter seats positioned behind one another in rows. Source: Dutch Safety Board

Based on the insights yielded by previous train crashworthiness studies[70] it is reasonable to assume that the different seat materials played a role in the occurrence of injuries. Plastic can crack and result in sharp edges. This occurred in the rear of the seats in the intercity and may have affected the nature and seriousness of the injuries sustained.

Figure 20: Top: the undamaged table in the section of the intercity where the passenger was fatally wounded; Bottom left: a folded table in the rear of an intercity seat; Bottom right: a deformed bar in the sprinter vestibule, probably bent in a collision with a passenger. Source: Dutch Safety Board

70 Safeinteriors, 2010. Train Interior Passive Safety for Europe – Publishable Final Activity Report. Specific Target Research Project (STREP). FP6-031-260.

Occupants of both trains also attributed their injuries to other parts of the interior, especially the tables and wastebaskets. The thin tabletop in the intercity is noteworthy in terms of crashworthiness (see figure 20, left). A thin tabletop can cause significant injuries even at a short distance, especially if it collides with a relatively vulnerable part of the body, such as the abdominal region.[71] On both trains, passengers travelling in the direction in which the train was headed reported injuries caused by tables. These injuries were caused by window tables and – in the intercity – foldable tables in the back of the seat in front.

The greatest collision speed in the intercity was in the first coach, which also experienced a downward movement during the collision (see also 4.3). Two occupants reported suffering severe internal abdominal injuries, which can be related to their contact with these tables. The passenger who later died from her injuries was also sitting next to the window in the first coach. With limited available space due to the nearby access door, this seating place consisted of a single seat rather than two adjacent seats (see figure 20, left). In addition to its thin tabletop, this seat had various other specific characteristics. In comparison with other seats, a larger part of the table overlapped with the passenger's body, as the seat did not have an armrest on the window side. The passenger in question was also leaning against the aisle-side armrest, as there was no second seat. This prevented the passenger from easily sliding past the side of the table.

In the other intercity coaches, collisions with tables resulted in injuries to the chest region rather than the abdominal region. This concerned both tables on the window side and foldable tables in the back of the seats in front of the injured passengers. Damage was clearly visible in several places (see figure 20, centre). The difference with the injuries in the first coach may be partly attributable to the fact that the first coach underwent a different trajectory to the coaches that became involved in the collision at a slightly later stage (see section 4.3.1), the difference in posture between the occupants and their slightly different movements during the collision. It is clear to see that a seemingly small difference can have major consequences bearing in mind that there are only a few centimetres between the sternum or lower ribs and the softer abdominal region.

Sprinter passengers also reported injuries as a result of the window side tables. All reported injuries were minor. The number of reported injuries was approximately one third of the number reported by intercity passengers.

A small number of occupants of both trains reported collisions with other interior components, such as waste bins and handrails in the vestibules. Passengers in the intercity also reported collisions with stair handrails and toilet doors, while passengers in the sprinter also reported collisions with glass partition walls. These interior components incurred especially significant damage in the sprinter (also see *Preventing objects from flying around the compartment* (c)). Several of these bars were visibly deformed (see figure 20).

71 NATO, 2007. Test Methodology for Protection of Vehicle Occupants against Anti-Vehicular Landmine Effects. Chapter 3 – Injury criteria and tolerance levels, 3.1 Injury biomechanics. NATO/OTA RTO-TR-HFM-090.

There was a risk of injury in both the intercity and sprinter in the form of sharp interior components and corners. Examples include coat hooks in the intercity and the corners of electronic information panels located above the passengers' heads in both trains. Although none of the respondents mentioned these sharp objects, corners and edges as the cause of their injuries, they do pose a significant safety risk. If circumstances had been slightly different (if, for example, the train had been more or less crowded) these sharp interior components could also have caused injuries during this collision.

The effect of objects flying around the compartment (c)
Interior components in both trains became partially dislodged during the collision. These components included inspection hatches, light boxes, chair fastenings, (parts of) glass partition walls, glass doors and partition wall fastening rods. Several light boxes in the intercity and one glass wall, one glass door and one armrest in the sprinter were entirely dislodged. The sprinter had a considerably larger number of glass components due to its open design concept. There was glass damage in both trains.

The front windshields on both trains shattered as a result of the collision. The intercity driver suffered several cuts to the face and head, probably caused by coming into contact with glass from the shattered windshield.

Glass damage was found in the area between the stairs and passenger compartment in two parts of the intercity. The safety glass used in the train, consisting of toughened glass[72], broke up into small, blunt granules (see figure 21). The doors between the first and second class compartments in the sprinter were made of toughened glass. Here too, one of the doors shattered into small pieces. Although a number of occupants were hit by these granules, none reported any injuries as a result of broken glass.

Glass partition walls in the sprinter were damaged. The partition walls next to the toughened glass doors are made of laminated[73], toughened glass. Although one of these walls had broken, the glass granules were held together by the layer of foil between the glass plates.

The other partition walls in the sprinter were made of laminated glass. Some walls were broken, however the shards of glass were held together by the layer of foil. Other walls had cracked windows with sharp edges. There were also loose shards and panes of glass that had been dislodged from the structures to which they were attached (see figure 21). Small shards of glass were also found on a number of chairs located directly behind the damaged glass vestibule partition walls. When passengers in the vestibules bump into the partition walls, this can cause glass shards to 'spall' from the rear side of the walls (known as the 'spall effect').

Under current regulations, the mandatory use of safety glass - either laminated or toughened glass – is not subject to any requirements regarding the context in which the glass will be used.

72 Toughened glass is approximately five times stronger than normal glass of the same thickness and will break into tiny granules rather than large shards, thus limiting the risk of injury.
73 Laminated glass consists of two or more panes, connected by a transparent and an invisible layer.

No requirements are imposed on the performance of the glass in the event of a collision, such as the load the glass must be able to bear, the consequences of a collision, and whether the glass must break or remain whole. From the perspective of crashworthiness and injury risk management, it is advisable to avoid the occurrence of sharp components (sharp edges, splinters) when glass breaks. It is also important that glass does not become separated from mounting points or foil layers and fly through the compartment in the event of a collision.

Figure 21: Glass damage. Top left: entrance to intercity passenger compartment; Top right: broken glass partition wall in sprinter; Bottom left: shattered glass door in sprinter; Bottom right: broken and dislodged glass shards in sprinter. Source: Dutch Safety Board

When used correctly glass can actually prevent injury, for instance if the glass or the structure to which it is attached yields to some extent. The current application of glass in the sprinter thus leaves some room for improvement in this area.

Applicable laws and regulations also specify that parts of the interior may not become dislodged in the event of a collision up to an acceleration of 5 g.[74, 75] Although several chair fastenings became dislodged during the collision on 21 April, the entire seating structure did not. Occupants did not report any injuries caused by dislodged chairs. One occupant reported injuries caused by lighter dislodged interior components. Such dislodged interior components - including inspection hatches, light boxes and armrests - were found in various parts of the two trains. If the trains had been more crowded, the falling ceiling components in the intercity in particular could have caused injuries.

The effect of safety systems (seatbelts and airbags) (d)
Safety systems in trains can improve crashworthiness, as described in 4.2.2. No specific safety systems, such as seatbelts and airbags, were found in either train. The use of such systems is also not compulsory under the current regulations. European-level studies on the effectiveness and applicability of such systems in trains are currently still ongoing.

The effectiveness of a safety system largely depends on how it is installed, maintained and used in a train. A system that is installed, used or maintained incorrectly can actually increase the risk of injuries. For example, a seatbelt requires adjustments to the design of the seat that could increase the likelihood of injuries if the seatbelt is not being used. [76, 77] Moreover, seatbelts naturally do not work for passengers who are standing. Finally, in the case of the intercity a seatbelt could have hampered the escape of the train driver and second man to such an extent that they could have become trapped.

4.5 Transport operator's safety policy

The two trains involved in the collision on 21 April behaved very differently, as the trains differ in terms of design. Their designs date from different time periods in which different regulations applied. The transport operator's policy also plays a role in determining why the trains 'are the way they are'.

The intercity involved in the collision was from the second VIRM series. This series was built according to the original design from the 1990s, when trains were not yet subject to any legal crashworthiness requirements. The design was based on internal crashworthiness guidelines applied by the NS, based on past accidents. These intercity trains are not equipped with energy absorbers. They also do not incorporate any measures to prevent

74 During the period 1998-2004, admission requirements were specified in: RnV M-001 Standard ´Admission Requirements for Rolling Stock Railway Safety´ prepared by RailNed Railway Safety (which later became part of the current Environmental and Transport Inspectorate).
75 As of 2005, admission requirements for trains refer to EN-12663 (Railway applications - Structural requirements of railway vehicle bodies).
76 RSSB, 2005. Engineering Improving the design of seats and tables, and evaluating restraints to minimise passenger injuries - Review of Two-Point Passenger Restraints.
77 RSSB, 2007. Research Programme Engineering Assessment of three-point passenger restraints (seatbelts) fitted to seats on rail vehicles.

trains from riding up over one another in the event of a collision. However, the structural load bearing requirements applied by NS at the time were more stringent than those set out in UIC leaflet 566. NS also required the manufacturer to subject the intercity prototype to static load bearing tests in order to demonstrate its compliance with load bearing requirements.

Passenger volumes rose dramatically around 2001. NS did not have sufficient rolling stock to meet rising demand. There was an urgent need for new rolling stock. NS decided to place a repeat order for more trains according to the original design of the first series, without imposing additional requirements on crashworthiness for instance based on changes in the laws and regulations. This decision was partly based on good experiences with this type of train. The Inspectorate for Transport, Public Works and Water Management (*Inspectie Verkeer en Waterstaat*, IVW) admitted the second series of VIRM intercity trains to the railway network based on the fact that they were identical to the previously admitted first series.

The sprinter involved in the collision was an SLT coach. The SLT coaches were designed around 2005 as part of a public tender held by NS. One of the conditions stipulated by NS was that the design was expected to meet the legal crashworthiness requirements which had by then been adopted.[78] This meant that the coach structure had to be resistant against the four collision scenarios (see 4.2.3). It also meant that the train was expected to comply with the latest version of EN 12663. The supplier was also expected to deliver the rolling stock along with the legally required admission documents[79], which served as a basis for the permit issued by the Human Environment and Transport Inspectorate.

During the construction and admission of both trains to the railway network, only limited requirements applied to the crashworthiness of their interior (UIC 566 and EN 12663 respectively). NS also did not specify any additional requirements. It is thus relevant to assess NS' policies regarding the minimisation of collision damage and managing the risk of injury to occupants. Since the introduction of the Railways Act in 2005, transport operators have been legally required to adopt a safety policy that covers the risk of collisions. Within the NS Group organisation, NS Reizigers is responsible for this as the train transport operator. NS' interpretation of this responsibility is expressed in the safety management system (SMS). This SMS relates exclusively to railway safety. Although the SMS defines railway safety as '*The extent to which danger in and as a result of the railway traffic system is absent*', whereby the term danger relates to injuries and damage,[80] the emphasis of all safety risk management measures is on collision prevention. Limiting the consequences of a collision and managing the risk of injury to occupants is not discussed in the SMS.

78 Before European standard EN-15227 entered into force, national regulations applied to the admission of trains in the Netherlands. Railned standard sheet M001 applied between 1998 and 2005, and the Rail Vehicle Inspection Decree (*Regeling Keuring Spoorvoertuigen*, RKS) was adopted on 1 January 2005. Both contained requirements regarding the crashworthiness of passenger trains.

79 The Safety Management System features a specific procedure for the purchase, modification, repair and disposal of rolling stock (Process 8.1), which outlines this working process.

80 The railway traffic system is defined as 'all people, resources and methods that directly contribute to railway traffic within a railway network'.

According to the minimum requirements applied by NS, all new trains must comply with current European laws and regulations and the relevant standards. This frame of reference also applies to workplace safety for train drivers and conductors and the safety of occupants. However, incidents within the NS organisation may prompt the introduction of additional requirements. Commercial interests also play a role in the purchase and modification of trains. NS strives to make train journeys as pleasant as possible and tailor its product to passenger needs where possible. The organisation applies three quality levels in this context: minimum quality, basic quality and comfort and experience quality. Every new and modified train must meet the minimum and basic quality standards in order to remain attractive to customers. Figure 22 shows the quality levels applied by NS.

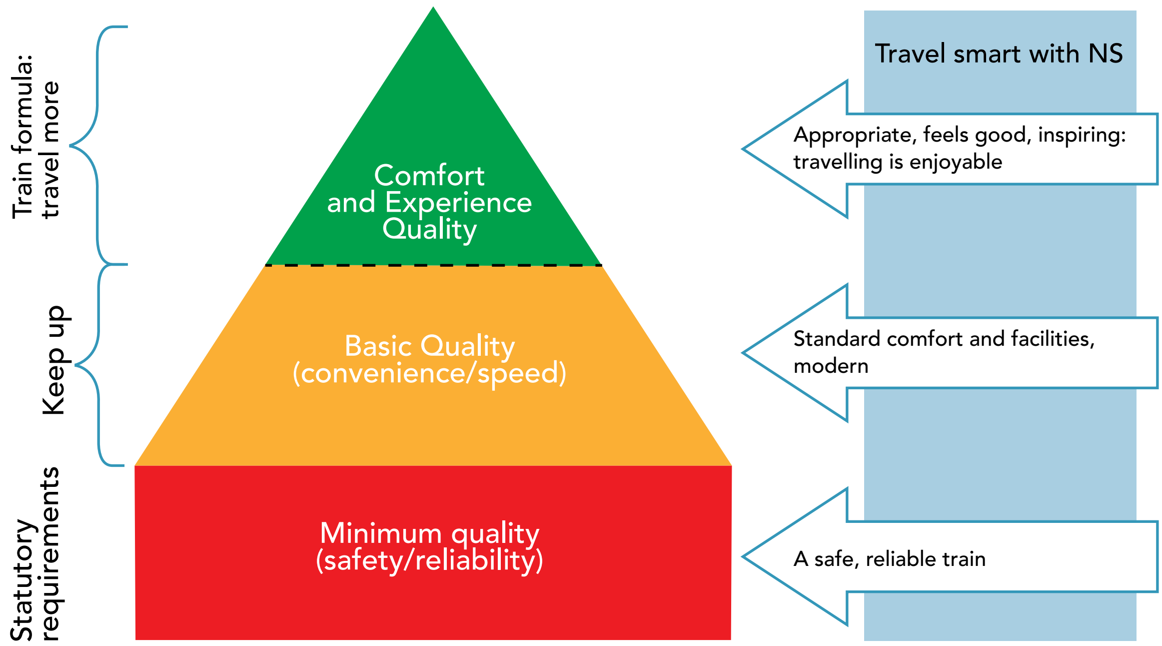


Figure 22: Quality levels. Source: NS.

Safety is one of the various considerations that play a role in the purchase and modification of trains. The NS' general statutory responsibility for safety[81] is reflected in its responsibility for social safety as included in the Transport Plan[82] for 2012, in addition to its responsibility for running to schedule, service (the provision of information and general cleanliness), a reasonable likelihood of obtaining a seat, and accessibility. Crashworthiness was and is subject to statutory minimum requirements.

4.6 The collision on 21 April 2012 in a broader perspective

The final section of this chapter describes the trains' collision compatibility, and discusses the transport operator's regulations and policies with regard to crashworthiness in greater detail.

81 Source: Transportation Act 2000 and Transport concession for the main railway network 2005-2015, Chapter II, Article 6.
82 NS describes how it intends to meet the obligations imposed in the concession in its annual transport plans.

These are two aspects of the collision on 21 April 2012 that the Safety Board feels warrant specific attention. The collision of 21 April will first be placed in a broader perspective by comparing the incident with previous collisions.

4.6.1 Train collisions from a historical perspective

After the accident on 21 April, it was stated that this was the only train collision in the past two decades to have resulted in a passenger's death. This could create the impression that the parties involved have since been relatively successful in their efforts to prevent train collisions and ensure the crashworthiness of trains. However, more detailed examination of the accident statistics yields a somewhat more nuanced picture.

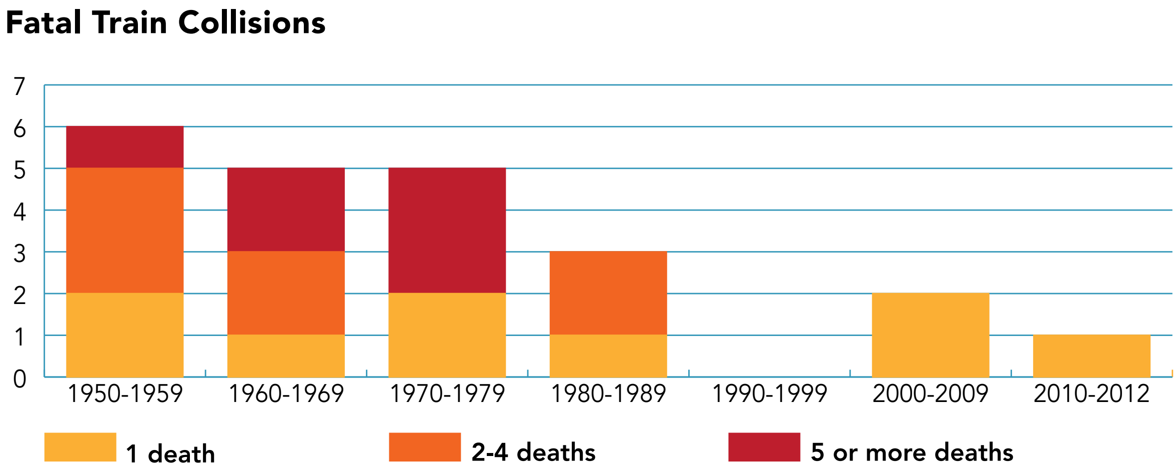


Figure 23: Fatal train collisions over time

The past sixty years have indeed seen a dramatic drop in the frequency of fatal train collisions. Figure 23 shows how the number of fatal train collisions has dropped from six to five per decade during the 1950s, 1960s and 1970s to a total of three over the past twenty years. There has also been a reduction in the severity of the collisions. Over the last twenty years there have been no train collisions with *multiple* passenger fatalities. The three fatal collisions that took place in the past twenty years all involved a single fatality; in two cases, this concerned the train driver while the third (the collision under investigation) involved a passenger fatality.

However, serious collisions involving passenger trains have continued to occur with some regularity over the past few years.[83] During the period 2001-2010, the number of collisions (and injured passengers) totalled:[84]

83 A passenger train is a train that runs on a scheduled timetable. Shunted trains, for example, are not regarded as passenger trains and have not been included in this elaboration.

84 These figures are based on annual trend analyses by the Human Environment and Transport Inspectorate (known as the Inspectorate for Transport, Public Works and Water Management until 2012).

- Sixteen head-on and thirteen side collisions between a passenger train and another train. All sixteen cases involved injuries, and six cases involved more than ten injured victims. There was one fatality during a collision in Roermond (2003).
- Several dozen of collisions between a passenger train and a buffer stop, of which eight were severe enough to result in injuries. None of the victims suffered fatal injuries.
- Many dozens of level crossing collisions with a passenger train, of which nineteen cases involved occupant casualties and/or train derailment. None of the victims on the train suffered fatal injuries.[85]

As these figures show, there has been an average of four to five serious collisions involving passenger trains per year, of which a substantial number resulted in injuries. It should be pointed out that some of these collisions would have had more serious outcomes if the course of events had been slightly different. This applies to the collisions with other trains and buffer stops, and the level crossing collisions (especially those that resulted in derailment). It should also be noted that there was a significant increase in the volume of rail traffic in the period 2001-2010.

4.6.2 Train collision compatibility

The damage to both trains as a result of the collision on 21 April clearly shows that the driver's compartment and the ends of the passenger compartments of the intercity were considerably more deformed than those of the sprinter (see section 4.3 and figure 24). This difference can be explained by the fact that the structural designs of the two trains were based on two fundamentally different concepts. The intercity's design dates back to the early 1990s, while the sprinter was designed in 2005. The interim period saw dramatic developments in the area of passenger train crashworthiness – in terms of the overall safety philosophy, technical possibilities and the regulatory framework. More information about the key developments can be found in Appendix 4.

Although the significant deformations of the intercity train did not result in the entrapment of any occupants during this collision, the Safety Board has identified three points of concern with regard to the damage sustained by the trains.

Incompatibility between the noses of the two trains (1)

The Dutch Safety Board is concerned by the fact that the sprinter's crash absorbers had very little effect. These crash absorbers were deformed during the collision due to the incompatibility between the intercity's nose and that of the sprinter (see figure 24). When purchasing new rolling stock, it is important NS checks whether there is any need for modifications in order to ensure collision compatibility with its existing fleet.

85 The Environmental and Transport Inspectorate's annual trend analyses show that the number of victims among the occupants of other vehicles involved in the level crossing collisions varies greatly from year to year. This information has therefore not been included in this report.

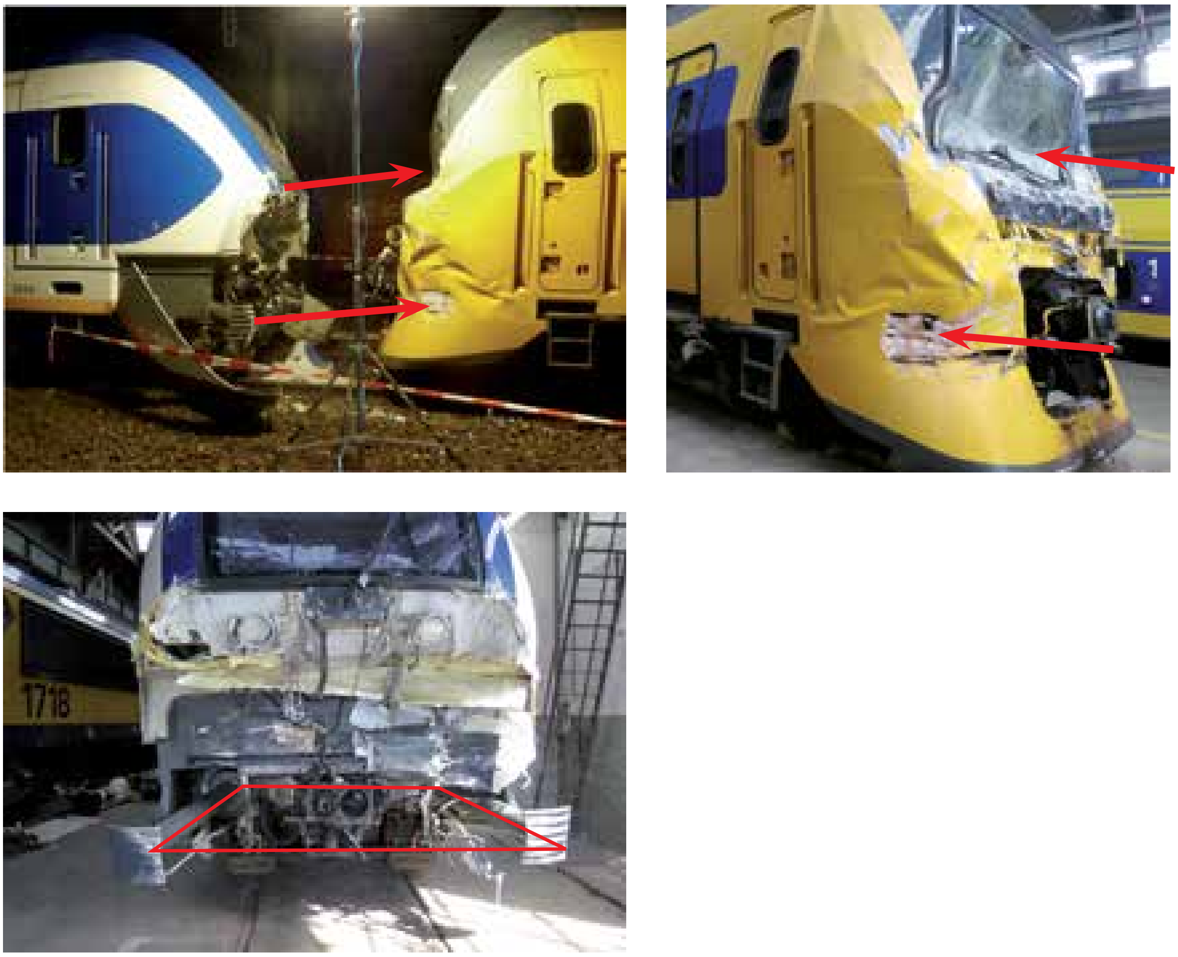


Figure 24: These photos show the incompatibility of the two trains. Top left: the final position with deformations caused by the collision. Top right: damage to the intercity's nose. Bottom left: the sprinter's crash absorbers, which bent outwards as a result of the collision. Source: Dutch Safety Board

Deformation of the intercity's driver's compartment (2)
The serious deformations of the intercity's driver's compartment represent a second point of concern. These deformations posed a serious injury risk to the two train drivers in the driver's compartment.

These deformations can be attributed to the fact that the intercity's nose was considerably less sturdy than the sprinter's at the point of impact. The area in question has been intentionally reinforced on all sprinter trains (and other passenger trains of recent design) in order to protect the driver's compartment against level crossing collisions with a truck.[86] The sprinter's driver's compartment, which was subjected to the same forces during the collision, did not suffer any substantial deformations.

The relatively weak upper section of the intercity nose can thus cause problems in the event of head-on collisions with another modern passenger train or level crossing collisions with a truck. The latter type of accident is especially common in practice.

86 This type of collision is one of the four collision scenarios used to assess whether the designs of new passenger trains comply with current admission requirements.

The photos below show two examples of a level crossing collision with a truck involving similar intercity trains that also resulted in major damage to the driver's compartment.

Figure 25: Examples of serious deformations of the driver's compartments of comparable intercity trains (VIRM) as a result of level crossing collisions with a truck; left: Maarheeze, June 2010; right: Wijhe 2005.

The Safety Board has not assessed the extent to which the risk of entrapment in the driver's compartment could be reasonably limited. Further research into this problem is essential in view of the fact that a considerable part of NS' fleet consists of VIRM trains which will be used on the railway network for dozens of years to come. Such research should also include the other 'old' train types in the current fleet. In the view of the Safety Board, NS bears primary responsibility for conducting such research in its capacity as owner/operator and user of the trains in question.

Failure of couplers between intercity coaches (3)
The failure of couplers between the individual intercity coaches during the collision represents the third point of concern. As a direct result of this failure, the front coaches experienced a greater secondary collision speed than the other coaches. The failure of these couplers also increased the risk of individual coaches riding up over each other or derailing. Neither of these phenomena occurred during the collision. However, the potential seriousness of these phenomena is so great that the Safety Board recommends further research in this area to assess the potential for improvement.

4.6.3 Crashworthiness: studies, policy and regulations
There are clear differences between the two trains in terms of crashworthiness. This can be attributed to the fact that one of the two (the sprinter) was designed and admitted to the railway network approximately fifteen years later than the other (the intercity). A large number of crashworthiness studies have been conducted in the interim period. New insights and techniques in the area of coach construction have since been applied in the design of new trains. Admission requirements for new trains have also been tightened on the basis of lessons learned. The sprinter involved in the collision was one of these new trains.

NS policy

The intercity involved in the collision is from the second VIRM series. This series is identical to the first VIRM series built in the period 1994-1996, when trains were not yet subject to any legal crashworthiness requirements.[87] When the second VIRM series was finally introduced, ten years later, NS did not take any measures to assess whether the coaches met the newly introduced crashworthiness regulations. It should also be noted that NS subsequently purchased a third series of the same type, during the same period that the sprinter trains were purchased. Unlike the sprinter, the design of the third series of intercity trains does not specifically take crashworthiness into account. The structure is identical to the original design from the 1990s.

Several modifications were made to the interior however, in response to previous collisions involving an intercity (Amsterdam 2004, Roosendaal 2004) in order to improve passenger safety. This mainly concerned the improvement of ceiling unit fastenings and inspection hatches, however various improvements were also made in the area of passenger comfort. These include individual reading lights in the first class coaches of the latest series of intercity trains. However, the hard materials used and the position of the reading light near to the passenger's head demonstrates that crashworthiness did not play a role in NS' decision-making process when ordering the trains in question.[88] Another example is the modification of the earlier intercity trains, where an air conditioning unit was placed on the driver's desk in the driver's compartment as a temporary solution. Remarkably, the lessons learned in terms of train interior crashworthiness are not reflected in the operational rolling stock and are not being applied by NS despite the fact that this information has been available for several years. Although this would constitute an important step towards fulfilling NS' responsibility for overall safety, limiting the consequences of a collision and controlling the risk of injury to occupants is not included in the SMS.

Rolling stock has a relatively long lifespan; passenger trains have an average lifespan of thirty five to forty years - or more, in some cases. The scheduled usage period for the second and third series of intercity trains extends to 2039/2041 and 2044/2045. The parties involved should thus ensure that their policies are aimed at implementing lessons learned and technical developments wherever possible. This applies to both the purchase of trains and any modifications. This attitude/interpretation of tasks on the part of the railway undertakings is actually required under the terms of the Railways Act.

Admission of the VIRM follow-up series

By the time the second and third series were purchased, legal admission requirements had been introduced in the area of crashworthiness (see Appendix 4). However, the Human Environment and Transport Inspectorate did not apply these requirements during the admission process. The Inspectorate categorised both repeat orders as 'follow-up construction' rather than 'new construction'.

87 Railned standard sheet M001 applied between 1998 and 2005, and the Rail Vehicle Inspection Decree (*Regeling Keuring Spoorvoertuigen*, RKS) was adopted on 1 January 2005.

88 NS has stated that it is now placing a greater emphasis on crashworthiness, for instance in the development of the specifications for the New Generation Sprinter (NGS) in 2012.

This implies that the second and third series of VIRM coaches were not assessed to verify their compliance with the applicable crashworthiness requirements at the time of their purchase and commissioning. The Safety Board has not been able to determine why the NS and the Inspectorate decided to purchase and admit the latest VIRM follow-up series in this manner.

Despite the lessons learned with regard to interior crashworthiness – information that has been available for some years now – no actual changes have as yet been made to the admission requirements. Current legislation on interior crashworthiness still refers to the UIC leaflets from the early 1990s. The TSI on Locomotives and Passenger Rolling Stock[89], which entered into force in the spring of 2012, will not be reflected in admission requirements until the underlying standards have been implemented at European level. However, the European Railway Agency (ERA) is currently overseeing efforts to do so. It is still expected to take several years until the planned additions to the TSI are actually implemented.

The Safety Board believes it is essential that interior crashworthiness regulations are tightened up as soon as possible. The Safety Board feels that the Minister of Infrastructure and the Environment should play a key role in this process. In the run-up to this European process, the Safety Board recommends that the Minister follows the British example by incorporating these tighter admission requirements into national legislation ahead of time.[90]

In conclusion
The Dutch Safety Board expects the parties involved to minimise risks as much as can be reasonably expected and to record measures to manage these risks in a demonstrable and realistic safety strategy. They must also continually tighten up this safety strategy on the basis of proactive risk analyses and the investigation of incidents and near accidents.

The Safety Board has concluded that the NS has for a long time neglected to include crashworthiness as an explicit part of its safety strategy. NS has insufficient insight into the risk of occupant injuries in the event of a collision and limits its control measures to the statutory minimum. This investigation has shown that the statutory minimum is insufficient. Based on its statutory responsibility for safety, NS has an individual responsibility to guarantee the safety of its staff and train passengers. In view of the above, the Safety Board is of the opinion that attention should be focused on improving the crashworthiness of trains.

89 Technical Specifications for Interoperability: European standards designed to facilitate cross-border rail traffic throughout Europe.
90 Standard GM/RT2100: Requirements for Rail Vehicle Structures (including interior crashworthiness).

4.7 Conclusions

The incident involved a sprinter and an intercity. The two trains collided at a closing speed of approximately 50 km/hour.[91] This speed was (well) above the collision speed (36 km/hour) for reference collisions as applied in the design/admission of new passenger trains. The collision on 21 April can thus be typified as a severe collision. The incident had serious consequences for the occupants: 1 fatality, 24 severely injured occupants and 165 occupants with minor injuries.

The key points for attention
Although the trains collided at a high speed, neither train was derailed. The trains were also not deformed to the extent that any occupants became trapped as a result. Nevertheless, there are a number of points for attention:

- The intercity's driver's compartment was deformed to the extent that both train drivers would have become trapped if they had not evacuated their seats on time. The ends of the intercity coaches also suffered significant 'uncontrolled' deformations.
- The couplers between the intercity coaches failed, causing the coaches to collide with one another. This resulted in uncontrolled deformation of the intercity coaches, while also increasing the risk of derailment. The latter is also reflected in the fact that the nose of the sprinter rode up over the nose of the intercity during the collision.

In the case of both trains, a number of the potential control measures had not been implemented or failed to perform as intended. This concerns modifications of both the train's structure and interior:

- Structure: the intercity had not been fitted with crash absorbers, either in the nose or between the coaches. Although the sprinter had been fitted with crash absorbers, some of these only functioned in part due to incompatibility with the intercity. This mainly applied to the crash absorbers in the sprinter's nose.
- Interior: occupants of both trains could be thrust over a relatively great distance in the event of a collision. This applied especially to the seats positioned across from one another and the open areas with standing places in the sprinter. A significant percentage of interior components with the potential to collide with occupants could also be rendered more collision-friendly, for instance by applying a shock-absorbent covering and removing any sharp or protruding edges. Specifically in the case of the intercity, there is potential for improvement in terms of the rear of the seats, the shape of the tables and the presence of an air conditioning unit on the driver's desk. It also emerged that the latches on some of the ceiling hatches in the sprinter had come open. As regards the sprinter, the increased injury risk due to the use of glass partition walls and doors is the main cause for concern.

91 50 km/h plus/minus 10 km/h: the calculated collision speed is an approximation of the actual speed.

Why potential safety measures were not implemented
The intercity's design dates back to the 1990s. Since that time, a great deal of insight has been gained and major technical advances have been achieved in relation to the crashworthiness of trains. The intercity coaches involved in the collision were brought into use in 2005 as repeat orders of the same coaches purchased in the 1990s. It is therefore not surprising that the intercity had not been updated according to the latest insights and technical possibilities, and did not meet the latest admission requirements. A third series of these intercity trains was purchased in 2008. Although this is legal, it means that the train fleet's crashworthiness is not being improved as quickly as it could be.

Two interrelated issues have meant that the interiors of both trains do not in all relevant aspects reflect the latest insights on crashworthiness:

- Despite extensive international research into the crashworthiness of passenger trains in recent years, the findings have not yet led to a tightening of the admission requirements that apply to train interiors. To date, only the admission requirements relating to the structure of the trains have been tightened up.
- NS felt it was sufficient to comply with the statutory minimum requirements in relation to crashworthiness of train interiors and neglected to impose any additional requirements, despite being required to do so under the Railways Act. A greater emphasis was placed on other aspects, such as the need for standing room, vandal-proof facilities, passenger comfort and social safety in the design of the train's interior. There is no evidence that the risks associated with these aspects in the event of a collision were taken into account. As a result of this outlook, NS failed to (fully) consider some of the available safety measures.

On the basis of all the findings, the Safety Board has reached the following conclusions:

1. **When it comes to the crashworthiness of its trains, NS does not take any measures above and beyond the concrete technical minimum requirements mandated by law. NS thus failed to take further measures in fulfilment of its statutory duty of care**

   This attitude had the following consequences in terms of the interior and structure of both trains:

   - The aspect of interior crashworthiness did not come into play when purchasing new trains.
   - When purchasing the follow-up series of intercity trains, NS did not make any efforts to assess whether lessons learned in relation to crashworthiness justified structural modifications, such as adjustments to the driver's compartment.
   - The procedure for purchasing new trains did not involve any assessment of the potential incompatibility between structural crashworthiness measures and the existing fleet. As the collision on 21 April showed, some of the modifications to the sprinter nose were only partially effective due to incompatibility with the intercity nose.

2. **The Minister of Infrastructure and the Environment has not incorporated lessons learned in the area of interior crashworthiness into the admission requirements for passenger trains.**

   An EU research project on this subject was completed in 2010, but the outcomes are yet to be translated into concrete European regulations or guidelines. Unlike UK standards, which do feature requirements in the area of train interiors, Dutch standards have not been designed to anticipate the outcomes of this research.

3. **The Human Environment and Transport Inspectorate has not held NS accountable for its failure to observe its statutory duty of care with respect to the general crashworthiness of its trains.**

   According to the Railways Act, NS bears a duty of care for the safety of its business activities. This means NS is required to ensure that all relevant safety risks are adequately controlled, and is responsible for determining which measures – in addition to those mandated by law – this will require. As indicated above, NS did not meet these requirements with regard to the crashworthiness of its trains. The Human Environment and Transport Inspectorate, the body responsible for monitoring compliance with the Railways Act, has not held NS accountable for this failure.

5 CONCLUSIONS

5.1 What caused the collision?

At least one hundred and ninety people were injured in the Amsterdam Westerpark train collision on 21 April 2012, one of whom died a day after the accident.

The collision occurred because the driver of the sprinter drove past a red signal. The train driver had been distracted and thought that the signal displayed yellow instead of red. The train driver's act, however, is not the only explanation for the collision. Precisely because an error is human, other measures also need to be in place, i.e. measures to prevent red signals from occurring, measures to ensure that a train driver's error is detected before an ensuing collision and measures to ensure that injuries are kept to a minimum if a collision occurs nonetheless. Such measures were either not in place, or were ineffective:

- The timetable for that day had been tightly scheduled, as a result of which numerous red signals were required throughout the day. A goods train deviated from the timetable, without ProRail checking whether this would cause problems further on. As a consequence of these two circumstances the sprinter was obliged to wait at a red signal.
- The train driver had made an error in observing the red signal and therefore thought that he no longer needed to stop. The train driver himself failed to notice that he had done so, possibly because the red signal was located in a curve and because the train driver had been distracted. After he had made the error, the train driver was also not given any warning that a red signal would follow, or that he had passed a red signal.
- The train did not come to a halt automatically. The red signal was not equipped with the Automatic Train Protection System – Improved Version (ATB-VV).
- No measures were in place to warn the other trains automatically or via traffic control that a train had driven past a red signal.

The situation in Amsterdam Westerpark was not unique. The circumstances that had occurred at this location occur regularly on the railways. The timetable is also adjusted on other days of the year and at other locations on account of engineering work. The measures that were not in place are also not in place elsewhere on the railways. The manner in which the various parties performed their work was no different from the usual.

5.2 What caused the injuries?

Measures designed to prevent injuries failed to function or only functioned partially, or had not been implemented at all. For example, the intercity train driver's compartment was highly deformed, thus reducing the amount of available survival space.

Although the train driver and the second man had evacuated their seats, they were injured nonetheless. Although the compartment of the sprinter driver remained largely intact, only part of the other on-board facilities aimed at cushioning the impact of a collision functioned as intended.

The train drivers, conductors and passengers were mainly injured as a result of colliding with interior components, such as small tables and glass panels, or with other passengers.

The investigation shows while the NS indeed adhered to the minimum legal requirements when purchasing or modifying trains, it did not conduct or commission any research itself to identify additional measures to help improve train safety in the event of a collision.

5.3 Main conclusions

The key question in this investigation focused on the effectiveness of the measures taken and the consideration given to these and other measures:

How did the parties involved control the risk of a collision resulting from a train driving past a red signal, and how did they minimise the risk of passengers and personnel sustaining injury in the event of a collision?

It is up to the railway undertakings to take all measures that can reasonably be taken to prevent accidents from occurring and limiting the ensuing consequences. Not only is this the Dutch Safety Board's view, but it is also required by law, which is known as the statutory duty of care. The railway sector parties themselves are required to assess which risks are involved in their business operations and how they can control them to the best possible extent.

The Safety Board believes that the railway sector parties' statutory duty of care includes taking every conceivable safety measure unless the parties are able to justify that the disadvantages outweigh the safety gains. During this investigation the Safety Board examined whether the railway sector parties take measures to control risks in the manner described above.

Conclusions regarding controlling the risk of a collision

1. **NS does not guarantee that after a train driver has passed a yellow signal he will fully focus his attention on the impending red signal. Moreover there is no technical device to alert the train driver that he is approaching a red signal, or to warn him if the train has passed a red signal.**

   - The train driver involved was experienced and had a good track record.
   - Stopping at a red signal is a critical event for a train driver: one single error can have fatal consequences. Everything should therefore be geared towards ensuring that the driver's attention continues to focus on the red signal.

- NS has set out rules governing the use of means of communication by the train driver during the train journey. These rules stipulate that a train driver who is approaching a red signal is only permitted to make a telephone call in the event of immediate danger. The NS believes the train driver has the professional competence and technical skills to decide whether one extinguished rear signal during daylight constitutes immediate danger, and therefore leaves this up to the train driver.
- NS does not provide train drivers any support, after they have passed a yellow sign, to alert them to imminent danger upon approaching a red signal. This type of support was actually provided in the past, but its effectiveness was very limited. Rather than improving the support provided, it was discontinued from 1994. The implementation of a more effective aid was in fact discussed in the years thereafter but has not yet materialised to date.
- The design of many areas of the current railway system is still such that after a train has passed a yellow signal, a single train driver error could cause the driver to drive past a red signal, and result in a possible collision.

2. **NS had adjusted the schedule on account of engineering work. The schedule conflicted with both ProRail's planning standards and those of NS. This made the schedule unnecessarily vulnerable to disruption on the day of the accident and in practice gave rise to red signals.**

- NS schedules its own train services and is required to comply with the planning standards set out by ProRail. In addition, NS uses its own planning standards, which in some situations are tighter than those of ProRail.
- The scheduling systems provide limited insight into the use of the railways and what is feasible or not feasible according to each specific situation. This consequently makes it difficult for the schedulers to assess whether a schedule is vulnerable to disruption.
- The schedulers were of the opinion that the scheduled situation was in accordance with the standard, but applied a situation-specific standard to a situation for which that standard was not actually intended.
- The NS safety management system does not contain any information concerning adjustment of the timetable in the event of engineering work. In the event the schedule is adjusted on account of engineering work, no risk analysis is performed and no control measures have been prescribed to ensure the safest possible schedule (to avoid interdependence between trains as much as possible, for instance).

3. **ProRail, as the party with ultimate responsibility for the planned schedule, does approve the timetable for the entire year but does not review the deviations from the timetable that are necessary from day to day implemented by the transport operators. The scheduling system does not clearly show during which period of time a specific section of the railway track is reserved for a train.**

    - ProRail's safety management system does not set out which risks could arise if transport operators adjust the timetable. In the event the timetable is adjusted no risk analysis is performed and no control measures have been prescribed to ensure the safest possible schedule (to avoid interdependence between trains as far as possible, for instance).
    - A comparative analysis with Germany and Switzerland shows that the scheduling system in the Netherlands does not use up-to-date techniques to calculate when a section of the railway track should be reserved for a train and when the train has cleared that particular section. This means that the Dutch system does not clearly show whether there are conflicts in the timetable.

4. **ProRail, as the party responsible for traffic control, attaches low priority to ensuring that train running schedules are kept free of conflict whilst the time trains are operating.**

    - The priority for ensuring train operations are kept free of conflict depends on the individual signaller or traffic controller and their workload.
    - Little coordination or collaboration takes place between the different traffic control areas. This induces conflict. If a train in one signaller's area deviates from the timetable, ProRail does not structurally review whether this will adversely affect rail traffic in the signaller's areas through which the train is due to travel later on.
    - Conflicts are not identified by the system with which the signallers and traffic controllers are required to work. A functionality that is able to identify such conflicts was intended to be incorporated when the current traffic control system was put into service and was tested around 1999 but never actually implemented.
    - The Automatic Route Setting System can induce conflict because in some situations it sets routes that do not correspond to the schedule.

5. **ProRail does not guarantee that the options available are deployed to help prevent a train from driving past a red signal or to help limit the ensuing consequences.**

    - ProRail did not equip the red signal with the Automatic Train Protection System – Improved Version (ATB-VV). The sprinter, which indeed featured this system, consequently did not come to a halt automatically.
    - A signaller does not have disposal of any adequate devices to alert him to the fact that a train has driven past a red signal. The 'Train has passed a red signal' functionality was available until 1997. The functionality was discontinued because it often inadvertently activated an unwanted intervention or warning. Since 2001 the Safety Board and its predecessors have repeatedly urged that an improved functionality be reintroduced but this has not yet materialised to date.

- The last signal for the intercity continued to display green after the sprinter had driven past the red signal. Different ways are conceivable for promptly switching the relevant signals to red in the event a train drives past a red signal. Since 2001 the Safety Board and its predecessors have repeatedly urged that this measure too should be implemented. The pros and cons substantiating whether or how this measure should be implemented have not been considered.

6. **The law requires that railway undertakings themselves determine what measures are appropriate to control their safety risks. They do not always do so in a manner enabling third-party review. This is not the focus of government supervision in practice.**

   - The Railways Act requires the railway sector parties to take every conceivable safety measure as part of their statutory duty of care unless the parties are able to justify that the disadvantages outweigh the safety gains.
   - It emerged from the Safety Board's investigation that the railway sector parties do not do everything reasonably practicable to prevent accidents, such as that at Amsterdam Westerpark, or at least are unable to justify why certain measures were not taken.
   - Supervision by the Inspectorate does not focus on reviewing whether the parties consider which measures are reasonably possible. Furthermore the Inspectorate takes the view that it does not have disposal of the means to enforce the law if the railway sector parties inadequately perform their duty of care.

Conclusions regarding the control of injury risk (crashworthiness)

7. **In respect of train crashworthiness, NS restricted itself to the concrete minimum technical requirements laid down by law. NS thus failed to further implement its statutory duty of care.**

   NS' stance had the following consequences in terms of the interior and structure of both trains:

   - The aspect of interior crashworthiness was not considered when purchasing trains.
   - When purchasing the next series of intercity trains, it was not examined to what extent the enhanced insights into crashworthiness would justify structural modifications, such as adjustments to the driver's compartment.
   - The procedure for purchasing new trains failed to include examining the potential incompatibility between structural crashworthiness measures and the existing fleet. As the collision on 21 April showed, some of the modifications to the sprinter nose were only partially effective due to incompatibility with the intercity nose.

8. **The Minister of Infrastructure and the Environment has not incorporated the enhanced insights into interior crashworthiness in the passenger train admission requirements.**

   In 2010 an EU research project was completed on the crashworthiness of train interiors. The results of the research have not yet been enshrined in European regulations or directives. Unlike the UK standards, which do stipulate requirements for train interiors, the Dutch standards do not anticipate the results of the EU research project.

9. **The Environmental and Transport Inspectorate has not called NS to account in respect of its statutory duty of care for train crashworthiness.**

   Under the Railways Act, NS has a duty of care for the safety of its business activities. In respect of its duty of care, NS is required to ensure that all relevant safety risks are adequately controlled. NS itself is required to determine which measures are required – in addition to those required by law. In respect of the crashworthiness of its trains NS failed to meet these requirements. The Environmental and Transport Inspectorate, the body responsible for monitoring compliance with the Railways Act, has not called NS to account in this regard.

6 RECOMMENDATIONS

The Safety Board has formulated the following recommendations.

Prevent trains from approaching yellow and red signals

1. **NS:** Ensure conflict-free scheduling, applying as a minimum requirement consistent compliance with the ProRail planning standards. In addition, perform systematic risk analyses to formulate measures - exceeding those set out in the planning standards - to ensure the safest possible schedule.

2. **ProRail:** ensure rail traffic is kept free of conflict during both scheduling and rail operations. This includes reviewing whether the schedule provided by the transport operators meets the planning standards, as well as identifying and resolving conflicts arising during rail operations in a reliable manner.

3. **Minister of, and State Secretary for Infrastructure and the Environment:** Focus on continuously reducing the number of conflicts during the actual operation of the timetable.

Prevent trains from driving past a red signal

4. **NS:** Prevent train drivers from from passing a red signal whilst not noticing this, by:

   a. implementing a system that issues a warning immediately when a train approaches or passes a red signal;
   b. employing more specific procedures in respect of a train driver's conduct after passing a yellow signal.

Prevent trains from colliding after a train has passed a red signal

5. **ProRail:** Ensure measures are in place:

   a. that warn signallers if a train drives past a red signal;
   b. to promptly switch signals to red for approaching or overtaking trains, if a train has driven passed a red signal.

Prevent injury in the event of a collision

6. **NS:** Incorporate the crashworthiness of rolling stock in the safety management system, such that it is taken into account when considering the purchase or modification of trains, and to ensure that reasonably practicable improvements regarding safety will be implemented.

7. **Minister of, and State Secretary for Infrastructure and the Environment:**

   a. Incorporate the knowledge that is now available on interior crashworthiness in the passenger train admission requirements.
   b. At the same time expedite the further implementation of European regulations in this area.
   c. Ensure that re-ordered trains meet the requirements for newly built trains prevailing at the time the order is placed.

8. **Bombardier / Siemens:** Perform an additional investigation (in respect of both the train structure and the interior) and incorporate the lessons learned from this accident in future train designs.

Administrative bodies to which a recommendation is addressed should state their position in respect of compliance with this recommendation to the relevant minister within six months of the date of publication of this report. Non-administrative bodies or persons to whom a recommendation has been addressed should state their position in respect of compliance with this recommendation to the relevant minister within one year of the date of publication of this report. A copy of the response should at the same time be sent to the Chairman of the Dutch Safety Board and the Minister of Safety and Justice.

APPENDIX 7: EXPLANATION OF THE INVESTIGATION

Reason for the investigation

At 18:22 on the evening of Saturday 21 April 2012, two passenger trains collided head on in the city centre of Amsterdam near Westerpark, between the stations Amsterdam Centraal and Amsterdam Sloterdijk. The two trains involved were:

- A sprinter, type SLT, comprising six coaches travelling from Rotterdam Central Station via Breukelen and Amsterdam Central Station to Uitgeest.
- An intercity train, type VIRM, comprising six double-decker coaches travelling from Den Helder to Nijmegen.

The site of the collision is also known as Singelgracht Aansluiting ('Singelgracht junction').

The collision was extremely serious, resulting in one fatality, 24 people seriously injured and 165 slightly injured. It fulfilled the criteria stated in the law for a compulsory investigation into the accident. The accident also gave rise to considerable public unrest.

Dutch Safety Board investigation

The Dutch Safety Board is charged with establishing the causes of accidents and near accidents, with a view to reducing the risk of similar events recurring or at least limiting the ensuing consequences. The Dutch Safety Board expressly does not seek to apportion blame as is the case in criminal investigations. Instead, the Safety Board is most concerned with answering the key question: 'What lessons can be learned from what occurred?'

In addition to determining the immediate cause of the train collision, the purpose of the investigation was to establish how the parties involved control the risk of a collision resulting from a train passing a red signal (sub-investigation 1). Additionally, the investigation examined what has been done to minimise injury among passengers and employees in the event of a collision (sub-investigation 2).

Method of analysis

Various investigative tools were used in the analysis. Both qualitative and quantitative analytical methods were used, including timeline analysis and TRIPOD Beta, a method for analysing incidents. This method provides a system for determining why any undesirable event was not prevented, which circumstances contributed to the event and, in turn, to which factors these circumstances can be attributed.

Additionally, the investigation involved simulations of collisions, literature research, interviews and a roundtable discussion. The literature research consisted of reviewing and analysing public information such as national and international laws and regulations, standards, frameworks and guidelines, as well as various publicly available and confidential documents obtained from the parties involved in the investigation.

Investigative approach sub-investigation 1: Relevant facts about the accident

Previous Safety Board investigations
During the investigation it soon emerged that the collision at Amsterdam Westerpark occurred as a result of a train passing a red signal.[92] The most recent train collision resulting from a train passing a red signal into which the Safety Board had conducted an investigation was the train collision at Barendrecht in 2009. The Safety Board approached that particular investigation in the following manner:

1. Preventing red signals from occurring:
   If a train does not come across a red signal en route, the train does not need to stop at a red signal.

2. Preventing trains from passing red signals:
   If a train driver does come across a red signal en route, measures are conceivable for preventing the train from passing the red signal.

3. Preventing a collision after a train has passed a red signal:
   Several possibilities exist for preventing an actual collision after a train has passed a red signal.

Strategy for controlling the risk of a collision
In this investigation the Safety Board investigated how the parties endeavour to prevent such collisions. How could the various undesirable events occur to result in this collision? What barriers failed or were not in place that could have prevented the incident? And why did these barriers fail or why were they missing?

a. Preventing red signals from occurring

   - *Preventing scheduling conflicts*
   - *Preventing conflicts during the operation / adjustment of timetables*

b. Preventing trains from passing red signals:

   - Preventing train drivers from falling ill
   - Employing an automatic train protection system
   - *Signal position / visibility*
   - *Preventing train drivers from being distracted / becoming distracted*

c. Preventing a collision after a train has passed a red signal:

   - *Opposite signal automatically switches to red*
   - *Intervention by signaller*

92 A number of other conceivable causes could be excluded; for details see Appendix 6.

All of the above points were examined in the Barendrecht report. The message in that particular report focused strongly on the Automatic Train Protection system (ATB) and its history. The investigation into the Amsterdam Westerpark train collision focused mainly on the barriers printed in italics. The investigation also examined whether the recommendations formulated in the previous investigation had been acted upon.

Focus, areas investigated and research questions
The sub-investigation focused on the following:

1. The scheduling of the adjusted train timetable and dealing with the impending conflicts (the allocation of capacity);
2. The operation / adjustment of the timetable by traffic control and the manner in which the traffic control system provided support (allocation of routes);
3. Position / visibility of the signals (design);
4. Alertness of the train driver / whether he was distracted (human factor).

The following key question was defined for the sub-investigation: *How did the parties involved control the risk of a collision resulting from a train passing a red signal?* The key question was elaborated in the following five research questions:

Relevant facts about the Amsterdam Westerpark train collision

- What happened exactly in the period starting ten minutes before the collision and ending shortly after the collision?
- What undesirable events occurred prior to the collision?

In-depth investigation into the relevant facts

- How did it come about that the schedule contained a red signal?
- What caused the delays to lead to a conflict?
- What caused the train driver to fail to stop at a red signal?
- What caused the train driver to fail to notice that he had driven past a red signal?
- What caused the train's failure to stop automatically at the red signal?
- What caused the signaller to fail to intervene in the thirty seconds between the train passing the red signal and the collision?

Broad investigation into the relevant facts

- How did ProRail and NS control the risk of collision in their scheduling processes?
- How did ProRail and NS control the risk of collision in their operating processes?
- What recommendations formulated in the Barendrecht investigation that were not acted upon played a role in this accident?

Investigative approach sub-investigation 2: crashworthiness

Assessment of injuries
General information was collected about the nature and severity of the injuries for the purpose of the investigation conducted into the injuries sustained by the occupants (passengers and personnel). Information was also collected about the circumstances in which injuries were sustained, according to the parties involved.

By establishing some broad links between the main characteristics of the trains and the injuries, it was possible to identify the most important mechanisms leading to different types of injuries. In most cases it was not possible to establish the precise location of those involved. The investigation is therefore primarily based on the main types of seats or standing places in both trains. In addition, background information obtained from literature on the crashworthiness of trains was used, including the European research projects Safetrain[93] and Safe Interiors[94].

The descriptions of the injuries, information on the possible causes and the location of the occupants at the time of the collision were also recorded in an anonymised database. The database contains information about various aspects of the collision (information on collision dynamics, damage to the structure and interior of the two trains and the injuries).

The collection and analysis of information about the injuries and how they occurred comprised the steps described below.

Step 1: Establishing the number of occupants and casualties

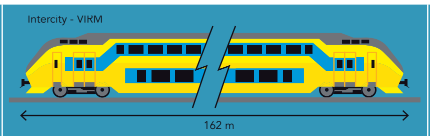
Number of occupants
The Safety Board estimates that the number of occupants on board the two trains totalled 425 people (3 train drivers, 2 chief conductors and 420 passengers). The estimate is based on registration data recorded by NS and the National Police Services Agency (KLPD) on the day of the accident. The estimated number differs from the actual number of occupants because not all passengers were registered and a number of passengers refused to give permission to pass on their particulars to the other organisations involved in the accident investigation, including the Safety Board.

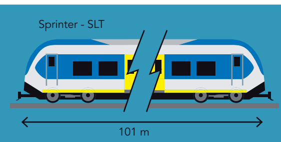
Based on NS and KLPD data, the Safety Board wrote to 416 people and received information from 245 people, 119 of whom stated that they had travelled with the sprinter while 125 people stated that they had travelled with the intercity service. In the case of one individual, it is not known on which train this person travelled. This therefore means that the actual number of occupants in both trains was higher.

93 Safetrain, 1997-2001. Train crashworthiness for Europe railway vehicle design and occupant protection (BRPR 970457).
94 Safe Interiors, 2010. Train Interior Passive Safety for Europe – Publishable Final Activity Report. Specific Target Research Project (STREP). FP6-031-260.

One train driver and one conductor were in the sprinter's cabin. The Safety Board assumes that there were at least 121 occupants in the sprinter. A train driver and a second man (mentor) were in the cabin of the intercity train. One conductor was also working on board the train. This takes the minimum number of occupants travelling on the intercity service to 128. The Safety Board has based this investigation on the minimum number of 121 occupants in the sprinter and 128 occupants in the intercity train.

Number of casualties
The exact number of injured people cannot be established because the precise number of occupants is unknown and it is not known whether they all suffered injuries. The Safety Board has taken the number of respondents who indicated that they had been injured in the train collision as the number casualties. Of the 420 occupants about whom the Safety Board has information, 186 people are known to have sustained injury, and one died as a result of injuries. Four NS staff members suffered injury, three of whom were train drivers and one conductor[95]. According to the Safety Board the number of people known to have been injured therefore totals 190. The actual number of people injured is probably higher. A breakdown of the people injured is shown in the table below for both trains.





	Total	No Injury	Minor	Serious	Died	No Injury	Minor	Serious	Died
Train drivers	3	0	1	1	0	0	1	0	0
Passengers	247[96]	35	82	8	1	25	81	14	0
Total	**250**[97]	**35**	**83**	**9**	**1**	**25**	**82**	**14**	**0**

Table 1: Overview of injuries in both trains (if known by Dutch Safety Board).

The reported injuries were classified as minor and serious according to the standardised injury scales used for the purpose of investigation and research into injuries suffered during transport accidents.[98] Minor injuries include injuries that heal quickly and do not affect or have a limited effect on the lives of the individuals involved, such as bruising, bleeding noses or grazes.[99] Serious injuries include injuries requiring treatment, such as fractures and internal bleeding.[100]

In parallel with the Safety Board's investigation, investigations were conducted by the Safety and Justice Inspectorate (*Inspectie Veiligheid en Justitie*, IVJ) together with the Dutch Healthcare Inspectorate (*Inspectie Gezondheidszorg*, IGZ) and by NS together with ProRail.

95 The conductor was in the passenger area of the train and is included as a passenger in all tables.
96 It is not known on which train one seriously injured person travelled.
97 It is not known on which train one seriously injured person travelled.
98 Appendix 7 provides information on the international standardised injury scales used in the field of traumatology and for this investigation, namely the Abbreviated Injury Scale (AIS) and the Injury Severity Score (ISS).
99 In injury scales: AIS 1 and ISS 1-3.
100 In injury scales: AIS ≥ 2 and ISS ≥ 4.

These investigations similarly identified those who sustained injury using the injury scales corresponding to the purpose of the investigations (how the emergency response efforts proceeded and indemnity respectively). The injury information was also gathered at different points in time and a different registration system was used for the persons involved. This means that no comparison can be made between the numbers stated in these investigation reports and the Safety Board's results.

The IVJ and IGZ investigations include a breakdown by hospital of the number of patients treated and admitted. On 21 April 2012, 117 people were treated in a hospital, 18 of whom were admitted for treatment.

The NS was approached by more than 300 people in total who suffered harm during the collision. Many of them indicated that they were injured and NS has subdivided the group on the basis of its own injury severity classification system[101]. Because both the source data and the classification system are different, the results cannot be compared to those of the Safety Board.

Step 2: Sources of information about injuries sustained by the occupants of both trains
Injury information was collected from four sources:

- Interviews (7) with NS employees who were on board the trains. These included the five employees working at the time of the collision and the two employees who were travelling as passengers. The interviews took place one day after the incident. Questions were asked about the course of events as well as the injuries suffered.
- Police reports/reports of interviews with occupants conducted by police officers on the scene of the accident, including descriptions of the course of the accident and the injuries sustained by occupants, as drawn up by the police on the scene of the accident.
- The autopsy report for the passenger who died, supplemented with oral information from passengers who were in the immediate vicinity of the casualty and from the emergency services.
- Questionnaires sent by the Dutch Safety Board. The questionnaire was sent to all occupants known to NS and the KLPD. The questionnaire was neither sent to the NS employees who were interviewed by the Safety Board nor to the deceased passenger's surviving relatives.

101 The categories used by NS are: Category 1: minor injury that will heal in a few weeks up to a maximum of two months; category 2: medium injury that will only heal two months to a year later and temporary incapacity for work; category 3: severe injury which will not heal or will only heal in the longer term, permanent disability and long-term incapacity for work.

The questionnaires contained questions regarding:

- Personal details (sex, age, height, weight)
- Location on board the train before the accident (which train, where in train/coach, standing or seated)
  - Questions for standing passengers: where, means of support.
  - Questions for seated passengers: type of seat, position relative to the direction of travel, seat occupancy.
- Injuries (separate questionnaire)
  - Activities immediately prior to the accident
  - Physical condition immediately after the accident (consciousness, pain, injuries)
  - Description of injuries (which part of the body and which side)
  - Description of how the injury occurred
  - Cause of the injury (fallen, knocked, hit by baggage)
  - Destination after the accident (hospital, first aid, GP, home)

The questionnaire was based on a questionnaire developed by the British Rail Accident Investigation Branch (RAIB) and other questionnaires used by the Dutch Safety Board in previous investigations into the consequences of two aviation incidents (Turkish Airlines and Onur Air). A simplified version of the questionnaire was used for this investigation as the questionnaires available were not entirely suitable for this particular investigation:

- The RAIB questionnaire was completed by those involved shortly after the accident and with assistance from police officers; the aviation incident questionnaires were completed together with a Dutch Safety Board staff member.
- The questionnaire was sent six weeks after the accident. Floor plans of the train coaches were not included as it was assumed that respondents would find it difficult to indicate where they were located on board the train. However, questions were included to obtain information about the characteristics of the occupant's seat or standing place and the occupant's surroundings.
- It was decided to ask people to describe their injuries in their own words and not to use a diagram of the human body for this purpose. However, the questions contained a number of references to help obtain information about the location where the occupant had been injured.
- The sample questionnaires contained questions about the emergency services. However, questions about the emergency services were omitted since they fall outside the scope of this investigation.

Permission to access the occupants' medical records was also sought in order to obtain information on the injuries sustained and to use the information for the purpose of the analysis, insofar as relevant to the investigation. Due to the personal and confidential nature of medical records, the greatest care must be taken in requesting access to medical records and using the information contained therein. Information obtained from medical records is therefore only ever used in incident investigations if the information is demonstrably necessary and the relevant insights cannot be obtained by other means.

While processing the information obtained from interviews and questionnaires, it became clear that detailed pathological and medical information would not be of any significantly greater value to the investigation than the information already provided by the persons involved. Therefore no use was made of the permission granted.

Step 3: Mailing of questionnaires
Two sources were used to send questionnaires to the passengers who had travelled on the sprinter and the intercity train: NS and the KLPD. Both organisations provided a list of passenger names and addresses.

- The first set of 311 questionnaires was sent in week 22 to the names and addresses provided by NS.
- A second set of 92 questionnaires was sent in week 24 to the additional names and addresses provided by the KLPD.
- Apart from the questionnaires sent on the basis of the information provided by NS and the KLPD, another 13 questionnaires were issued or sent to passengers whose names had been obtained by other means.

The questionnaire was sent to a total of 416 people.

A number of people were not included in the address files partly because some passengers had not been registered by the police and because a number of other passengers had not given the police permission to pass on their particulars to the other organisations involved in investigating the accident.

Step 4: Processing the information collected
The information was processed in the following manner:
- Transfer of the information provided into an anonymised Excel database
- Coding the nature and severity of the injuries based on the RAIB, AIS and ISS systems to enable comparison of the injuries sustained by the various individuals. See also Appendix 7, 'Injury Scales'
- The information provided about the severity and nature of the injuries was broadly correlated to information about the occupants' surroundings and the damage inside the trains on the basis of biomechanical assumptions. The available information contained insufficient detail to enable further analysis.

Step 5: Presentation of the results of the crashworthiness investigation
The results of the crashworthiness investigation are presented in two ways.

1. The investigation report contains the findings and conclusions of the analysis of the data collected. Based on these findings, the report sets out criteria for the parties involved on improving the crashworthiness of trains.
2. A data set contains factual information on the collision. This data set is intended to enable railway undertakings and railway vehicle engineers to conduct additional research into possibilities for improving crashworthiness, for example through specific simulations or crash tests.

Investigations commissioned by the Safety Board

The Dutch Safety Board commissioned various sub-investigations, the findings of which have been incorporated in the Safety Board's investigation.

Arcadis	Fact gathering
Intergo	Human factors
Lucros	Analysis of Train Event Recorder data
Delta Rail	Crashworthiness
TNO	Coding injuries, interior safety, simulation of collision

Guidance Committee

The Safety Board established a guidance committee for the purpose of this investigation. External members holding relevant expertise for the investigation comprised this Guidance Committee, in which they participated on a personal capacity under the chairmanship of two Dutch Safety Board members. The Guidance Committee convened on four occasions during the investigation to share information with the members of the Dutch Safety Board and the project team on the purpose and results of the investigation. The Committee acted in an advisory capacity during the investigation. Final responsibility for the report and the recommendations lies with the Dutch Safety Board. The composition of the committee was as follows.

Guidance Committee members:

J.P. Visser (Chair)	Dutch Safety Board
A. H. Brouwer-Korf (Vice Chair)	Dutch Safety Board
F.G. Bauduin	Deputy Justice, Arnhem Court of Appeal
W.A.G. Döbken	Former Director, NS and High Speed Alliance
G. Eijkelkamp	Syntus safety expert and former train driver
A. Kruyt	Chair of ROVER, Public Transport Passenger Association
P.M. Ranke	Former Director, Railned
P.W. van der Vlist	Former Regional Director and Head of Rail Safety, ProRail Traffic Control
J. Wismans	Professor of Vehicle Safety

Project team

Project team members

J.J.G. Bovens	Investigation Manager
R.J.H. Damstra	Project Leader
B.M.L.D. Renier	Investigator
T.T. van Prooijen	Investigator
A. van der Kolk	Investigator
G.J. Oomen	Investigator
A.B.M. van Overbeek	Investigator
A.C.J.G.M. van Roosmalen	Investigator
A. Sloetjes	Investigator
J. van den Top	Investigator
E.J. Willeboordse	Investigator
H.J.A. Zieverink	Investigator
E. Cillessen	External Investigator
N.J.A. Kuijper	External Investigator
L. Vermeulen	External Investigator

APPENDIX 8: RESPONSES TO THE DRAFT REPORT

In accordance with the Dutch Safety Board Act, a draft version of this report was submitted to the parties involved for review. The parties were requested to check the report for any errors and ambiguities. The draft version of this report was submitted to the following parties for review:

- the train drivers involved
- the signaller involved
- NS
- ProRail
- Bombardier / Siemens
- the Ministry of Infrastructure and the Environment and the Environmental and Transport Inspectorate (ILT)

All the above parties responded. The responses received were grouped into the following two categories:

- The Safety Board has incorporated corrections of factual inaccuracies, additional details as well as editorial comments, where relevant. The relevant passages were amended accordingly in the final report. These responses have not been separately included.
- The Safety Board replied to the responses that were not included in the report. These responses are set out in a table that can be found on the Dutch Safety Board's website: www.safetyboard.nl. In addition to the verbatim content of the responses, the table also provides the following information: the section relevant to the response, the party providing the response and the Safety Board's reply.

APPENDIX 9: REFERENCE FRAMEWORK

The Dutch Safety Board employs its own reference framework for the purpose of its investigations. On the basis of the reference framework the Safety Board examines whether and how organisations undertake responsibility in applying the principles of safety management.

General principles underlying the reference framework
The Dutch Safety Board acknowledges that there is no such thing as a society that is not subject to risk. Accordingly, the Safety Board basically assumes that things may go wrong in any process, which may directly or indirectly lead to exposure to risk or harm. Such events are rarely due to malicious intent on the part of the officer involved, who usually acts with the best of intentions. Rather than ascertaining what 'rule was breached' that contributed to the incident, the Dutch Safety Board seeks to ascertain what factors caused the act despite the good intentions. The risk of future accidents will be reduced by knowing and tackling these underlying factors.

To prevent exposure to risk, and to protect persons and goods from the consequences of risks that are already present, parties must ensure that they control their processes. The parties do not only have an individual responsibility, they also have a collective responsibility for the system as a whole. Parties are, for instance, required to collectively control the risks if one party is exposed to a risk which may have consequences for another party, or if the other party can precisely help to control the risk caused by the party responsible.

The Dutch Safety Board embraces the principle that the responsible parties should reduce risk as far as is reasonably possible. In other words, they should always ensure that they take the measures available to reduce risk unless this involves demonstrably unreasonable costs or other negative consequences. The measures may focus on preventing the occurrence of undesirable events, or on limiting the ensuing consequences.

Safety management priorities
The Dutch Safety Board has defined a number of safety management priorities in its reference framework. In all of its investigations the Safety Board examines the extent to which the organisations involved in the incident under investigation have implemented these priorities.

The Safety Board's reference framework embodies the following safety priorities:

Insight into risks serving as a basis for safety strategy
In order to achieve the required level of safety, the system should first be reviewed, after which an assessment of the associated risks should be performed. This will serve as a

basis for establishing which hazards need to be managed and which preventive and repressive measures are required be taken.

Demonstrable and realistic safety strategy
In order to prevent and manage undesirable events, a realistic and practicable safety strategy or safety policy should be defined. Safety strategy should be adopted and controlled at management level and is based on the following:

- the relevant laws and regulations;
- the applicable industry standards, guidelines and best practices, the organisation's own views and experiences and the safety objectives drawn up specifically for that organisation.[102]

Implementing and enforcing safety strategy
The following elements play a key role in implementing and enforcing safety strategy, and in controlling the identified risks:

- a description of the manner in which safety strategy should be implemented, focusing on specific objectives and plans, including the resulting preventive and repressive measures;
- a transparent, clearly-defined allocation of responsibilities on the 'shop floor' for the purpose of implementing and enforcing safety plans and measures, which information is available to all;
- a clearly documented definition of the required staff and necessary expertise in the various roles;
- clear and active central coordination of safety activities.

Tightening safety strategy
Safety strategy should be continuously tightened on the basis of the following:

- performing risk analyses, observation rounds, inspections and audits (proactive approach); periodically and/or whenever the basic principles are modified;
- a system for monitoring and investigating incidents, near accidents and accidents, and an expert analysis thereof (reactive approach). This will serve as a basis for carrying out evaluations and for the adjustment of safety strategy by management.

Leadership guidance, commitment and communication
The management of the parties and organisations involved should ensure the following:

- that, internally, expectations regarding safety objectives are clear and realistic;
- a climate conducive to the continuous improvement of safety on the shop floor, in any event by leading by example;
- that sufficient manpower and resources are made available;

102 In this context, see also the Third Framework Memorandum concerning Safety in Rail Traffic (*Derde Kadernota Railveiligheid*) which sets out government rail safety policy for the period 2010-2020 (Lower House of Dutch Parliament, session year 2010 - 34715).

- clear external communications concerning general procedures, the relevant assessment method, the procedures to be followed in the event of deviations and so on, based on clearly defined and documented arrangements with local parties.

The Safety Board understands that the nature and size of the organisation should be taken into consideration when assessing how an organisation implements safety management.[103] Opinion formation may therefore vary in respect of each incident. The underlying philosophy, however, remains the same and the expectations described above remain in force (as do the applicable statutory obligations).

Similar principles constitute the basis of countless standards and requirements applied by organisations in all levels of society for the purpose of organising their safety management systems. The activities performed by a certain party may sometimes pose risks to another party, or another party may specifically undertake to reduce that risk, in which case the parties carry collective responsibility for controlling the risks.

The five safety management priorities formulated above apply equally to the individual responsible for managing the system. After all, he or she also has a process that involves the organisation and modification of a system for which he or she is responsible. In this process it is equally important to ensure that all risks are controlled to the best possible extent and that this is implemented systematically.

103 This aspect has also been incorporated in the Railways Act: Section 33 (3) sets out that the safety management system of a railway undertaking should correspond to the nature and size of the undertaking.

APPENDIX 10: LAWS AND REGULATIONS

Statutory framework governing the rail sector in the Netherlands
Legislation has been drawn up at both European and national levels aimed at establishing a safer railway system. The European Union has drawn up various directives, the most relevant of which is the EU Railway Safety Directive. The EU member states are required to transpose the European directives into national laws and regulations. In the Netherlands the Railways Act provides for the safety of the main railway network. The Act has been implemented by means of various decrees and regulations. The statutory framework within which the Dutch rail sector operates is summarised in figure 1 below.

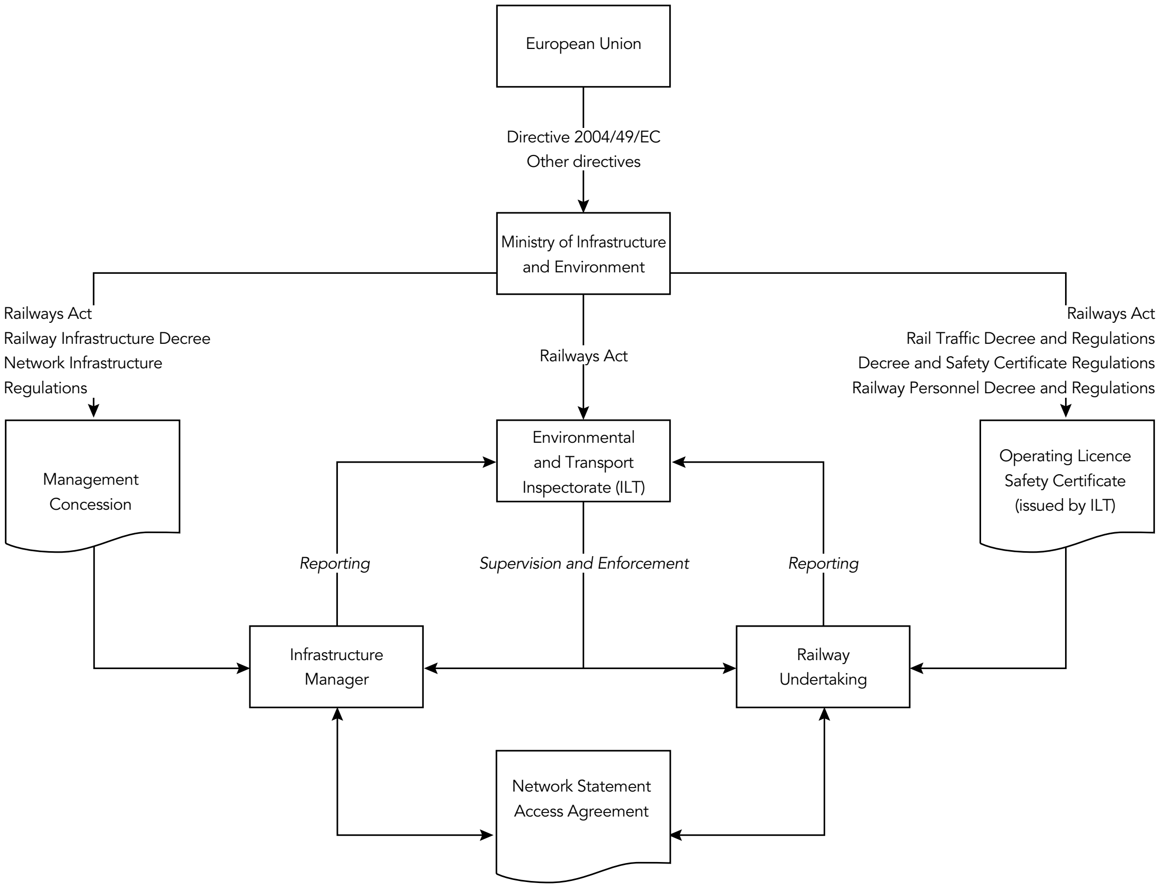


Figure 1: Relevant laws and regulations

European Directives

The aim of the European Railway Safety Directive 2004/49/EC (hereinafter: the Directive) is to establish a safer railway system as a whole.[104] The Directive sets out which safety targets the EU member states are required to pursue, and which safety indicators and measurement methods are used to determine whether these targets have been achieved.

Pursuant to the Directive, in order to develop and improve rail safety the EU member states have been charged with the following tasks:

- ensure that responsibility for the safe operation of the railway system and the control of risks associated with it is borne by the infrastructure managers and railway undertakings.
- they are required to implement the necessary risk control measures, where appropriate in cooperation with each other, to apply national safety rules and standards, and to establish[105] safety management systems.[106]

Lastly, the Directive sets out the following concerning the responsibilities of the various parties involved in respect of rail safety:[107] *'All those operating the railway system, infrastructure managers and railway undertakings, should bear full responsibility for the safety of the system, each for their own part. Whenever it is appropriate, they should cooperate in implementing risk control measures.'*

Railways Act

The Railways Act governs the construction, management, accessibility and use of the railways as well as rail traffic. The Act makes a distinction between responsibility for the infrastructure, on the one hand, and responsibility for transport, on the other.

The Minister of Infrastructure and the Environment grants a concession for the management of the main railway infrastructure to one or more infrastructure managers.[108] In addition to ensuring the quality, reliability and availability of the railway infrastructure, management of the infrastructure also covers the allocation of capacity and traffic control. The Minister has attached conditions to the concession to ensure that:

- the infrastructure can be used safely and efficiently;
- the safety risks associated with in the use and management of the infrastructure are analysed;
- suitable measures have been taken to ensure that safety risks are adequately controlled;[109]

104 Interoperability Directives 1996/48/EC and 2001/16/EC also cover safety management systems and therefore also relate to rail safety.
105 The European Directive uses the term safety management system (*veiligheidsbeheerssysteem*) while Dutch laws and regulations use the term '*veiligheidszorgsysteem*' (literal translation: safety care system). Other government and rail sector documents mainly use the term safety management system (SMS), which term is also used in this report.
106 Section 4, European Railway Safety Directive (2004/49/EC).
107 Railway Safety Directive 2004/49/EC, consideration 7.
108 Section 16 Railways Act.
109 Section 17 (1) (subsections b and c) of the Railways Act.

Thereby taking account of the expected specific operational requirements and the state of the art. The above conditions are set out in the management concession,[110] which also stipulates that the manager must have available an adequate safety management system which meets specific requirements.[111]

The Minister of Infrastructure and the Environment has delegated rail transport to the railway undertakings. An operating licence is required in order to operate a railway undertaking.[112] Railway undertakings are furthermore required to hold a safety certificate[113] to use the main railway infrastructure. The operating licence and the safety certificate are granted by the Human Environmental and Transport Inspectorate (*Inspectie Leefomgeving en Transport*, ILT) on behalf of the Minister. A safety certificate is granted on condition that the company is able to demonstrate sufficiently that - by applying an adequate Safety Management System - it is able to use the railway safely.[114] The Act imposes functional requirements on the Safety Management Systems used by railway undertakings.[115] Among other things, the system must guarantee that the railway undertaking:

- *'will not incur damage, nor unnecessarily obstruct or endanger anyone and will ensure that rail traffic can be handled without disruption as far as possible during normal business operations and in the event of foreseeable deviations from normal business operations;*
- *will take account of specific requirements if normal operations affect the operations of other rail users or the infrastructure manager;*
- *has identified the associated operational risks and will take appropriate measures to control these adequately, thereby taking account of the state of the art, the knowledge available within the sector and the guidelines for ensuring safe operations;*
- *will establish and enforce procedures for taking corrective measures in the event of deviations and incidents, as well as ensure continuous improvement of the level of safety with a view to changing circumstances, and based on the experience gained;*
- *will ensure that employees working in a safety role have gained the required work experience, and pursue the required further education or additional training and studies with a view to maintaining their suitability, knowledge and professional competence for the performance of the relevant role.'*

The Railways Act furthermore imposes education and suitability requirements on personnel working in a safety role[116] and to rolling stock driven on the railway.[117]

110 The management concession for the railway infrastructure was granted to ProRail for the period 1 January 2005 to 1 January 2015.
111 Section 3 and Article 7 Management Concession for the railway infrastructure.
112 Section 27 (2) (a) of the Railways Act.
113 Section 27 (2) (b) of the Railways Act
114 Section 32 (1) (b) of the Railways Act.
115 Article 33 (2) of the Railways Act.
116 Sections 49 and 50 of the Railways Act.
117 Section 36 Railways Act.

As stated above, the Railways Act provides that the infrastructure manager and the transport operators must 'take appropriate measures to adequately' control the safety risks. The Second and Third Framework Memoranda concerning Safety in Rail Traffic, which set out government policy on railway safety, elaborate on what this means, and this ties in with the Railways Act and the management concession. The framework memoranda state that the ALARP principle[118] is the applicable standard for ensuring that safety risks are adequately controlled. This principle means that the responsible parties must ensure that the available measures are taken unless these involve demonstrably unreasonable costs and/or consequences.

Decrees and regulations deriving from the Railways Act

The Railways Act has been implemented in various decrees and regulations. The decrees and regulations relevant to the investigation are summarised below.

Railway Infrastructure Decree and Network Infrastructure Regulations

The Decree primarily sets out provisions relating to the inspection, certification, maintenance and repair of the main railway infrastructure and the protection of the main railways and the surrounding area. The Regulations describe aspects, including which basic technical requirements the main railway infrastructure is required to meet.

Among other things, the Regulations lay down that the network infrastructure[119] safety system must guarantee separate routes for trains.[120] The Regulations also provide that the safe condition of the routes is to be communicated to train drivers by means of signals or cab signals.[121] The Regulations furthermore provide that the relevant section of the network infrastructure must be equipped with a train protection system which transmits information about the applicable signals to rail vehicles (broken down into speed stages of at least 60-80-130-140 km/h).[122]

Rail Vehicles Inspection Decree and Regulations (until March 2012)

One of the provisions of the Regulations provides that locomotives, trains, cab control cars and exceptional vehicles must be equipped with an Automatic Train Protection System (ATB) compatible with the ATB system on the main railway infrastructure. On route sections carrying the new generation ATB (ATB-NG) this does not apply to vehicles that are incapable of travelling faster than 40 km/h. The Rail Vehicles Inspection Decree and Regulations (*Besluit en Regeling keuring spoorvoertuigen*) were replaced by the Rail Vehicles Commissioning Regulations (*Regeling indienststelling spoorvoertuigen*) effective 5 March 2012.

118 As Low As Reasonably Practicable.
119 Section 7 of the Railway Act provides that sections of the main railway network where trains are permitted to travel faster than 40 km/h should be equipped with a protection system.
120 Section 13 (1) Network Infrastructure Regulations.
121 Section 13 (2) Network Infrastructure Regulations.
122 Section 14 Network Infrastructure Regulations.

Rail Vehicles Commissioning Decree and Regulation)
The Rail Vehicles Commissioning Regulations provides that locomotives, trains, control cars and exceptional vehicles must be equipped with an Automatic Train Protection System (ATB) compatible with the ATB system on the main railway infrastructure[123]; on route sections featuring the New Generation ATB (ATB-NG) this does not apply to rail vehicles that are incapable of travelling faster than 40km/h.

Operating and Safety Licence (Main Railways) Decree and Safety Certificate (Main Railways) Regulations
The Decree sets out further rules for the operating licence and the safety certificate. The operating licence provides admission to the profession of railway operator. However, the licence alone does not provide access to the main railways. The Railways Act contains additional conditions, including the requirement for a safety certificate. Safety requirements are set out in both the operating licence and the safety certificate. The difference between the two is that the safety requirements stipulated in the operating licence relate mainly to the railway undertaking's internal organisation, whereas the safety requirements in the safety certificate are geared towards safe participation in day-to-day rail traffic.

The Safety Certificate (Main Railways) Regulations further implement a number of provisions relating to the assessment and issue of the mandatory safety certificate for railway undertakings. The Regulations stipulate among other things that the Safety Management System:[124]

- provides for establishing an adequate safety policy;
- provides for the registration method for irregularities, the method of assessment of potential risks, the manner in which risk assessment is updated and ensures that compliance with the Safety Management System is monitored;
- ensures that documented rail safety regulations are updated;
- ensures that staff working in a safety role are properly trained and continue to be properly trained and that rolling stock always meets the statutory requirements;
- ensures proper internal communication procedures are in place concerning rail safety risks.

Rail Traffic Decree and Regulations 2011
The Rail Traffic Decree and Regulations set out further provisions for the safe and unhindered use of the main railway infrastructure. These cover aspects such as train composition, driving speed and the position of signals. The provisions concerning the position of signals are particularly relevant to this investigation. They relate to signal position and visibility. They also provide that a train should in principle always stop at a signal displaying red.[125]

123 Section 26 Rail Vehicles Inspection Regulations The Rail Vehicles Commissioning Regulations entered into force on 1 April 2012, just before the accident occurred.
124 Section 2-8 Safety Certificate (Main Railways) Regulations.
125 Annex 4 to Article 24 (1) of the Rail Traffic Regulations.

Only if the signaller issues a 'stop signal instruction' is the train driver allowed to pass that particular signal.[126] Appendix 4 of the Rail Traffic Regulations contains further details of the nature, implementation and meaning of signals.

Railway Personnel Decree and Regulations
The Decree provides that the drivers of rail vehicles must meet a number of general knowledge and competence requirements.[127] The Decree also provides that individuals working in a safety role (including train drivers) must meet medical and psychological suitability standards[128] and are required to undergo a medical and psychological examination. Medical and psychological suitability are required to be demonstrated based on relevant statements. The statements have a limited period of validity, which varies according to the train driver's age.[129] Once personnel have acquired the specialist knowledge required to perform the safety role they have in mind, they must subsequently ensure they retain the same level of knowledge. To that end, their proper professional performance is periodically assessed.[130]

The Railway Personnel Regulations implement four areas of the Railway Personnel Decree in detail: the examination procedure, the medical and psychological suitability requirements and the practical training programme for trainee train drivers.

Crashworthiness Regulations
The following regulations are relevant to the crashworthiness of passenger trains:

- *Construction*
  The current structural crashworthiness requirements are set out in the RIS, the TSI on 'Locomotives and Passenger rolling stock' and in EN standards 15227 and 12663. In essence the requirements stipulate that in order for new passenger trains to qualify for admission, it must be demonstrated that their design is able to withstand four crash scenarios. These requirements constitute the end result of a development programme that commenced in the eighties and saw completion a few years ago. The requirements were implemented in stages from 1998 (via Railned standard sheet M001 and the Rail Vehicles Inspection Regulations). Only internal NS rules and regulations applied until 1998.

- *Interior*
  The current interior crashworthiness requirements are set out in the TSI on 'Locomotives and Passenger Rolling Stock', which only describes a few specific aspects (fastening of objects and the safety characteristics of glass applied in the structure) but does not provide any generic requirements for train interiors. As far as these aspects are concerned, like the preceding regulations, the TSI refers to EN standard 12663 and UIC leaflet 566. The TSI also states that the ERA is currently heading up a study on formulating further regulations.

126 Section 3 of the Rail Traffic Regulations. These types of instructions are only issued for manually operated signals.
127 Section 24 Railway Personnel Decree.
128 Chapter III Railway Personnel Decree.
129 Section 31 and 32 Railway Personnel Decree.
130 Section 39 (1) Railway Personnel Decree.

However, the way in which this has been phrased would seem to suggest that it could still take several years to realise the additional regulations intended by TSI. The basic requirements for certain interior components (e.g. the seats) are set out in UIC leaflet 566. Reference has been made to this particular UIC leaflet in the regulations as far back as 1990, when the third edition of the standard was published.

Company rules

In addition to the above laws and regulations, the railway undertakings have established internal procedures and rules aimed at controlling the risks associated with rail traffic and/or ensuring uniform procedures. Among other things, the planning standards applicable to designing the timetable, the Train Driver's Manual (*Handboek machinist*) and the Signaller's Manual and Procedures (*Handboek & werkwijze treindienstleider*) are relevant to this investigation.

The planning standards are set out in a Network Statement which the railway infrastructure manager is required to draw up each year. The Network Statement contains information about the conditions providing access to the railway infrastructure, including the planning standards entailing requirements with which a timetable must comply. These requirements relate to the logistics process in particular; they pertain to the question of whether the infrastructure can be utilised in the scheduled manner without one of the trains encountering a red signal according to schedule.

Regulations governing the crashworthiness of passenger trains

The trains involved in the collision on 21 April 2012 date from different periods: the intercity train was designed in the early 1990s and the sprinter around 2005. The intervening period was characterised by far-reaching developments. In terms of organisation NS has changed, its views and the state of the art in respect of crashworthiness have changed as have the corresponding regulations.

Research and enhanced insights

Until some 30 years ago the view predominated that trains should be built as robustly as possible and that they should carry an obstacle deflector. The robust construction would prevent the train from sustaining severe deformation as much as possible in the event of a collision. The obstacle deflector was designed to prevent objects from ending up underneath the train, (and potentially derailing the train). The 1970s and 1980s saw a progressive awareness of other methods of possibly improving crashworthiness. Domestic railway undertakings initially undertook to research this topic themselves, it being customary at the time for railway undertakings to design their own trains. Particularly SNCF (France) and BR (England) led the field in crashworthiness.

NS also developed a vision for passenger train crashworthiness at that time. Initially NS endeavoured to bring about improvement by introducing defined crumple zones in passenger trains. The concept was actually applied in a few series of trains, such as the SM'90 and DM'90.

In addition, structural principles were applied that were designed to ensure that passenger compartments would remain intact as much as possible in the event of a collision. These principles broadly entailed the following[131]:

- Coaches must have a homogenous structure; passenger compartments should be sturdier than cabins and vestibules. The coach extremities must deform at a definably lower longitudinal compression force than the passenger compartments.
- Cabins must be able to withstand non-extreme collisions, and in the case of extreme collisions should distribute the collision forces throughout the entire structure.
- The end walls of coaches must be fitted with collision pillars to counter the consequences of overriding. The purpose is to prevent coaches from overriding each other and telescoping during a collision.

The crumple zone principle was later abandoned.

At that time, these principles were implemented in the internal NS rules and regulations, which also made reference to UIC leaflet 566,[132] an international standard (the third revised version of which was published in 1990) which sets out structural capacity requirements for coaches as well as requirements for several interior aspects (chiefly relating to the fastening of objects and the safety characteristics of glass applied in the structure). In essence, the structural capacity requirements for coaches set out in UIC leaflet 566 stipulate a capacity to withstand certain static longitudinal forces.

From the early 1990s, European railway operators began to pool their efforts to improve passenger train crashworthiness. The first major contribution was made through a large-scale research project carried out by the European Railway Research Institute (ERRI) in the first half of the 1990s,[133] aimed at enhancing the crashworthiness of passenger trains. Laying the foundation for this project was a detailed analysis of approximately two thousand train accidents that had taken place in various European countries (in the 1980s and first half of the 1990s) and an overview of the know-how available at the participating railway undertakings (including SNCF and BR). The study culminated in 1994 with a published report (ERRI report B 205; still frequently cited today). The key study findings were as follows:[134]

- *Construction*
  In the vast majority of train accidents (70%), the occupants can be effectively protected through the use of Crash Energy Management (CEM). This means that trains should be constructed so that in the event of a train collision maximum crash energy is absorbed by the crash absorbers or crumple zones, thereby limiting the level of the deformation forces.

131 Source: Memorandum on structural admission requirements for coach bodies (TC/96/R/33 from NS Materieel Engineering).
132 UIC stands for International Union of Railways (*Union Internationale des Chemins de fer*). Established in 1922, the aims of the UIC are to standardise the technical requirements for rolling stock, promote partnerships between railway undertakings and in so doing facilitate cross-border rail traffic.
133 ERRI stands for European Rail Research Institute. The institute conducted joint research projects and operated within the UIC. Its activities were discontinued on 30 June 2004; the reports produced have since been managed by the UIC.
134 Source: ERRI report B 205/RP1.

The underlying philosophy is that this will not only prevent the cabins and passenger compartments from deformation but that the occupants will also be subjected to smaller forces and decelerations.

- *Interior*
  The interior must be designed in a way that minimises the possibility of serious injury in the event of an 'internal collision' (occupant against interior elements). This includes the use of relatively soft materials for surfaces and avoiding sharp and/or projecting elements.

The report further stipulated the development of design criteria constituting collision scenarios for collisions between trains and collisions between trains and road vehicles (collisions on level crossings), to replace the standard static tests (based on UIC 566) previously used.

Safetrain
Insights from the ERRI study were worked out in greater detail in the large-scale Safetrain project led and funded by the European Commission, and sponsored by UIC. The project was carried out by a consortium of railway undertakings, train manufacturers, technical universities and research centres. The project was launched in 1997 and its final results were published in 2001.

In accordance with the ERRI study findings, the Safetrain project focused on both the construction and the interior. The ERRI findings were elaborated in the following two ways: formulating design criteria by means of collision scenarios and developing technical solutions.

The key findings of the Safetrain project are summarised below:[135]

- *Construction*
  Four test scenarios were formulated for the design criteria for the structural crashworthiness of trains:
  – scenario 1: train collides with a comparable train at a speed of 55 km/hour
  – scenario 2: train collides with a buffered 80-ton rail vehicle at a speed of 36 km/ hour
  – scenario 3: train collides with a fixed 16.5-ton object at a speed of 100 km/hour
  – scenario 4: pushing load on the obstacle deflector.

  Explanation: Scenario 1 was selected because the majority of seriously injured casualties result from head-on collisions between trains. Scenario 2 represents collisions between conventional trains (which tend to ride up over each other) and buffer stop collisions. Scenario 3 is intended to simulate a train collision at a level crossing with a truck, and scenario 4 to simulate a train collision at a level crossing with a small road vehicle (passenger car, motorcycle or moped).

135 Source: 'Safetrain and Safetram Projects: 'Results and Objectives' and 'Safetrain Project Results and Rail Passive Safety Harmonisation'.

- *Interior*
  The Safetrain project also focused on train interior improvements and to that end a list of best practices was drawn up. Research was also conducted into the best way to formulate interior crashworthiness regulations.

  In respect of the latter, a longitudinal acceleration pulse was defined for the purpose of testing the interior components and the way they had been fastened. The method is similar to the method used in other transport sectors, including road traffic. The longitudinal acceleration pulse was defined on the basis of a series of train crash tests using the above reference collisions for the construction of the train (collision scenarios 1-3). The acceleration pulse was broadly defined as an acceleration/deceleration of roughly 5-7 g within a time span of 110-210 milliseconds, which represents an abrupt change in velocity of around 30 km/hour. To test the interior crashworthiness of trains, maximum values were also defined for mechanical loads exerted on occupants if the compartment or cabin in which they are situated is subject to such an acceleration pulse. These load limits were defined for the head, neck, thorax and legs.

Regulations and admission procedure
In respect of the regulations and admission procedures, generally speaking the following three periods can be distinguished: the period prior to 1998, the period 1998-2005 and the period from 2005. The division relates to the unbundling of NS as referred to earlier (from around 1998) and the entry into force of the new Railways Act on 1 January 2005.

Period until 1998
Up until 1998, train crashworthiness was an internal affair of the former NS organisation which had not been split up. Although the admission of rolling stock (both procedures and requirements) was regulated by the Railways Act (of 1875), implementation had been fully delegated to the NS. At the time, the requirements consisted of the above internal NS rules and regulations (including the reference to UIC leaflet 566 in respect of the structural capacity of coaches). A special (one-man) office within the NS, called *Bureau Materieel Toelating* (BMT), was in charge of the admission of new rolling stock.

Period from 1998 - 2004
In 1998 the process described earlier of splitting off NS into infrastructure managers and transport operators, and into contractors and engineering consultancies was set in motion. A dedicated independent inspection authority was established at the same time in the form of Railned Spoorwegveiligheid, which drew up a range of regulations for the admission of rolling stock. Most important in the present context are regulations RN-M001 and RN-M005, stipulating technical requirements and the admission procedures, respectively.

The technical crashworthiness requirements (summarised in RN-M001) basically comprised a codification of the internal NS rules and regulations that were in effect up until 1998, including the reference to UIC leaflet 566. The RN-M001 standard sheet also stated that new international crashworthiness requirements were under development, meaning the Safetrain project described in the previous section. The standard sheet announced that the future requirements would consist of crash tests.

In anticipation of the new crashworthiness requirements that were due to be introduced, the standard sheet (RN-M001) incorporated two further crashworthiness requirements in addition to the 'old NS requirements'. The first requirement stipulated that coaches must be constructed to allow no deformation of either the cabin or the passenger compartments in the event of a head-on collision with another train at a speed of up to 36 km/hr. The other addition was a loosely worded requirement stating that interiors must be designed to avoid injury (by avoiding sharp/projecting elements or the possibility that components can come loose or break off).

Independent inspection authorities were charged with testing these requirements for the admission of new rolling stock.

Period from 2005
On 1 January 2005 the new Railways Act replaced the original Railways Act of 1875. Railned Spoorwegveiligheid merged into Inspectorate for Transport, Public Works and Water Management (IVW), a supervisory Rail authority).[136] The procedures and technical admission requirements have since been incorporated in the new Railways Act (together with the corresponding Regulations). Requirements for the admission of new rolling stock are assessed by certified inspection authorities (known as Notified Bodies).

The Railways Act of 2003 stipulates that new trains must meet the requirements set out in Annex III of European Directive 2001/16/EC. Implementation of the requirements is detailed in the following documents: the national Regulations[137], a set of Technical Interoperability Specifications (TSIs) drawn up under the auspices of European Railway Agency (ERA) and a set of European (EN) Standards. The crashworthiness of passenger trains as set out in the TSI on 'Locomotives and passenger rolling stock'[138] and EN Standards 12663-1 (*structural requirements of railway vehicle bodies*) and 15227+A1 (*crashworthiness requirements for railway vehicle bodies*) are particularly relevant to this investigation.[139]

The essence of the current requirements for the *structural* crashworthiness of rail vehicles is summarised in four scenarios based on the results of the Safetrain project. New passenger trains are required to demonstrably withstand the following:

- a collision with an identical train at a speed of 36 km/hour;
- a collision with a buffered 80-ton carriage at a speed of 36 km/hour;
- a collision with an obstacle (15-ton truck model) at a speed of 90 km/hour;
- a 300/250 kN longitudinal force exerted on the obstacle deflector (at 0/75 cm from the centre).

136 Effective 1 January 2012, the Inspectorate for Transport, Public Works and Water Management (IVW) and the Housing, Spatial Planning and the Environment Inspectorate (VI) merged into the Human Environmental and Transport Inspectorate (ILT).
137 Initially the Rail Vehicles Inspection Decree (*Regeling Keuring Spoorvoertuigen*, RKS), which was replaced by the Rail Vehicles Commissioning Regulations (*Regeling indienststelling spoorvoertuigen*, RIS) effective 1 April 2012.
138 The TSI entered into force on 26 May 2011.
139 These two EN standards entered into force in 2010 and 2008, respectively.

The passenger compartments and vestibules in scenarios 1-3 may only be subjected to a certain degree of deformation, while the amount of space in the cabin must meet certain minimum requirements to ensure that the train driver has sufficient space to survive the impact. Furthermore the average acceleration of the cabin and compartments may not exceed 5 g in scenarios 1 and 2 and 7.5 g in scenario 3, for the entire duration of the collision. Moreover, in test 1 (despite a vertical displacement of 40 mm between the colliding trains) the trains must not ride up over one another, and at least one wheelset per bogie must stay in effective contact with the rails.

The TSI on 'Locomotives and passenger rolling stock' merely makes reference to EN 12663-1:2010 in respect of the strength requirements for the framework and the fastening of fixed components in the passenger area of the rail vehicle body.

APPENDIX 11: PARTIES INVOLVED AND THEIR RESPONSIBILITIES

ProRail (infrastructure manager)
ProRail is an organisation responsible for managing the railways. The Minister of Infrastructure and the Environment has awarded the management concession for the railway infrastructure for the period from 1 January 2005 to 1 January 2015 to ProRail.[140] As holder of the management concession, ProRail bears sole responsibility for performing the statutory obligations to which the manager is subject.

ProRail is tasked with operating the railway network, maintaining the railway network and, if the central government so decides, expanding the railway network. ProRail divides the capacity of the railway network between the various goods and passenger transport operators. Consequently, ProRail is also responsible for traffic control.

As manager of the infrastructure, ProRail is responsible for ensuring that the infrastructure can be used safely and effectively. This responsibility is elaborated further in regulations in the management concession. For example, under the management concession ProRail is required to analyse the safety risks associated with the use and management of the main railway infrastructure and take appropriate measures to control these risks adequately, thereby taking account of the expected specific operational requirements and the state of the art.[141] This means that ProRail must also take account of risks caused by factors outside ProRail's direct sphere of influence.

Under the management concession, ProRail must (commencing 1 January 2008) have in place a safety management system (SMS) that complies with the requirements stipulated in the Railway Safety Directive.[142] These requirements stipulate, among other things, that ProRail must ensure that:

- procedures and methods are in place for assessing and controlling risks if new risks associated with the infrastructure or the operational activities arise as a result of a change in the operating environment or as a result of new equipment;
- procedures are in place which ensure that accidents, incidents, near accidents and other hazardous incidents are reported, investigated and analysed and that the necessary preventive measures are taken;
- provisions are made for performing periodic operational audits of the SMS.

140 Decision of the Minister of Transport, Public Works and Water Management concerning the management concession for the main railway infrastructure; decision of the Minister of Transport, Public Works and Water Management of 3 May 2007 concerning the amendment of the management concession for the main railway infrastructure.
141 Section 3 Management Concession for the main railway infrastructure.
142 Section 17 Railways Act in conjunction with Section 7 (1) of the Management Concession for the main railway infrastructure.

Dutch Railways (*Nederlandse Spoorwegen 'NS'*)
The two core tasks of NS are: passenger transport – including train maintenance – and junction development in station areas, with the main focus of NS' operations being the transport of passengers by rail. This activity has been delegated to the business unit NS Reizigers BV. NS has a concession for the main railway network and for a number of local train services.

NS is a railway undertaking. A railway undertaking has no access to the main railway network if:[143]

- the undertaking does not hold a valid operating licence;
- the undertaking does not hold a valid safety certificate or test certificate;
- the undertaking is not insured against risks related to statutory liability;
- the right to that access does not arise directly from an access agreement as referred to in Section 59 of the Railways Act;
- the undertaking is otherwise not entitled to use the main railway network.

The Minister of Transport, Public Works and Water Management grants an operating licence if the railway undertaking meets the requirements of reputation, financial capacity and professional competence. Furthermore, the company must be sufficiently insured against statutory third-party liability.[144] In order to obtain a safety certificate, the railway undertaking must demonstrate that:[145]

- it has effective safety management in place as referred to in the Railways Act;
- it is able – through its safety management – to safely use the railway and is able to comply with the safety regulations prescribed by or pursuant to the Railway Act.

If the undertaking is able to meet all requirements, the Transport, Public Works and Water Management Inspectorate awards a safety certificate on behalf of the Minister of Transport, Public Works and Water Management.

Railway undertakings must have in place a safety management system (SMS) that guarantees, among other things, that:[146]

- it has identified the operational risks involved and will take appropriate measures to control these effectively, thereby taking into account the state of the art, the knowledge available within the sector and the guidelines for ensuring safe operations;
- it establishes and enforces procedures for taking corrective measures in the event of deviations and incidents and ensures continuous improvement of the level of safety bearing in mind changing circumstances and based on its experiences;
- it has procedures in place with regard to services and goods connected to railway safety delivered to the railway undertaking by third parties.[147]

143 Section Article 27 (2) of the Railways Act.
144 Section Article 28 (1) of the Railways Act.
145 Section Article 32 (1) of the Railways Act; Section 16 (4) Operating and Safety Licence (Main Railways) Decree.
146 Section Article 33 (2) of the Railways Act.
147 Section 7 Safety Certificate (Main Railways) Regulations.

The Railways Act therefore stipulates that the railway undertakings must adequately control the safety risks using appropriate measures.[148] This also includes risks caused by factors outside the transporter operator's direct sphere of influence. The transporter operator is obliged to take account of these risks in any risk analysis and take any measures necessary to mitigate them.

The railway undertaking must ensure that drivers of rail vehicles meet the stipulated requirements regarding suitability, knowledge, competence and experience and that they hold a certificate proving their medical and psychological suitability. Persons in safety critical positions (including train drivers) must undergo a medical and psychological examination. Medical and psychological suitability should be demonstrated based on relevant statements. These certificates have a limited period of validity that depends on the age of the driver.[149]

The Ministry of Infrastructure and the Environment

The Railways Act (2005) stipulates that the Minister of Infrastructure and the Environment bears system responsibility for railway safety. Consequently, the Minister is responsible for formulating policy, the operation of the statutory frameworks and initiating new laws and regulations.[150] The Railways Act also stipulates that the Minister of Infrastructure and the Environment is to supervise compliance with the rail safety provisions under or by virtue of the Railway Act. The Minister has delegated this supervisory duty to the Environmental and Transport Inspectorate (ILT).

Under the Railways Act, railway undertakings are responsible for the safety of day-to-day operations within the frameworks defined in the Act. The railway companies have a duty of care for safety. The railway undertakings must, both individually and collectively, ensure the safety risks are adequately controlled (which also includes the crashworthiness of trains) by taking appropriate measures. The Third Framework Memorandum concerning Safety in Rail Traffic[151], which sets out government policy on railway safety, elaborates on what this means. This framework memorandum states that the ALARP principle[152] is the standard applied for the adequate control of safety risks. This principle means that the responsible parties must ensure that the available measures are taken unless these involve demonstrably unreasonable costs and/or consequences.

According to the Railways Act, railway undertakings must have an effectively functional safety management system (SMS) for controlling railway safety. The functioning of the SMS is assessed by the Inspectorate on a regular basis.

148 The ALARP principle also applies here as a criterion for *adequately controlling risks*.
149 Section 31 and 32 Railway Personnel Decree.
150 Ministry of Transport, Public Works and Water Management, Transporting safely, working safely, living safely with the railways (Veilig vervoeren, veilig werken, veilig leven met spoor). Third Framework Memorandum concerning Safety in Rail Traffic, June 2010, p. 24 (Lower House of Dutch Parliament, session year 2009-2010, 29893, no. 106).
151 Ministry of Transport, Public Works and Water Management, Safety on the rails. *Second Framework Memorandum concerning Safety in Rail Traffic*, November 2004 (Lower House of Dutch Parliament, session year 2004-2005, 29 893. nos. 1 and 2); Ministry of Transport, Public Works and Water Management, Transporting safely, working safely, living safely with the railways (*Veilig vervoeren, veilig werken, veilig leven met spoor*). *Third Framework Memorandum concerning Safety in Rail Traffic*, June 2010 (Lower House of Dutch Parliament, session year 2009-2010, 29893, no. 106).
152 As Low As Reasonably Practicable.

An overview of the legislation is included in Appendix 4.

The Environmental and Transport Inspectorate (Inspectie Leefomgeving en Transport 'ILT')

The Environmental and Transport Inspectorate supervises compliance with the relevant legislation and regulations and enforces them through inspections, granting licences and knowledge transfer. The aim of supervision is to minimise the risk of accidents, environmental pollution and distressed market conditions. The ILT supports and reinforces the willingness of parties who are subject to supervision to perform their obligations. Supervision in the rail sector focuses particularly on the aspect of safety and less so on environmental pollution and distressed market conditions.

The responsibility for the ILT falls to the Minister of Infrastructure and the Environment. The Inspectorate uses three methods to ensure that railway undertakings comply with laws and regulations: through service provision, supervision and investigation. The Inspectorate also conducts investigations into accidents, incidents or irregularities. Within the context of this investigation, it is the supervisory task of the ILT that is of particular relevance.

The Inspectorate supervises the following:

- the rail infrastructure;
- the manager of the railway infrastructure;
- companies that offer transport services using the railway infrastructure;
- certain officials who work on the railway infrastructure in a professional capacity;
- vehicles that run on the railway infrastructure;
- companies that carry out inspections of the infrastructure, vehicles or persons;
- companies that train personnel and are authorised to administer examinations.

ILT is also responsible for the safety certificates that it awards to railway undertakings on behalf of the Minister of Infrastructure and the Environment. Furthermore, the Inspectorate assesses whether the safety management systems of railway undertakings and the infrastructure management are satisfactory. In addition to safety certificates, the ILT also issues licences for rail vehicles and grants any exemptions.

One of the ILT's tasks as referred to above is the supervision of bodies designated by the Minister of Infrastructure and the Environment to inspect and certify new and modified infrastructure as well as new and modified rail vehicles. There are currently six such designated inspection bodies in the Netherlands. These inspection bodies have been notified to the European Union as Notified Bodies.

APPENDIX 12: RED SIGNAL PASSING HYPOTHESES

The Safety Board has established that signal 494 for the sprinter displayed red. The driver of the sprinter has stated, however, that he saw that signal 494 displayed yellow. The reason for this difference in observation cannot be determined with certainty. The Safety Board has, however, excluded a number of causes and determined a number of possible explanations, which are set out in this appendix.

Excluded causes

Driver incompetence
There is no evidence that points to the driver of the sprinter being unwell or being incapable of driving the train prior to the collision. The driver had ten years' experience and drove the route in question daily. Two days before the collision the driver had had a day off work, and he also indicated that he started work on the day in question feeling rested and relaxed. There is no evidence that the driver was under the influence of medicines, drugs or alcohol.

Glare
The sun was virtually due west at an altitude of 21 . The sun shone diagonally from the left at an angle of approximately 50° to 40° (the angle varied owing to a curve in the railway track). The cabin design of the sprinter is such that the maximum angle the driver can look either left or right is approximately 25°. Consequently, it is out of the question that the driver was hindered by glare when he approached the red signal.

Field of vision from the sprinter cabin
The sprinter is a relatively recently constructed new train. This is the first serious collision involving this type of train. One striking feature of the design of the sprinter is that the driver has a boxed range of vision. This is mainly due to the absence of side windows and the fact that the driver is seated relatively far behind the windscreen. The Dutch Safety Board therefore had the cabin design assessed by an ergonomics consultancy. The assessment shows that the field of vision had no influence on the occurrence of the collision.

Extinguished signal
The colour the signal was displaying at the moment the driver looked at it cannot be determined. Signal 494 was visually checked following the collision on 22 April 2012 at around 01:20, when it was established that the signal displayed red light.

Train brake defective / rails slippery
Both trains deployed emergency brakes shortly before the collision and the required braking force was duly supplied,[153] meaning that the brakes functioned.

Revocation of route section
Train traffic control had not set a route section for the sprinter. So, consequently, no route section was revoked for the sprinter.

Electromagnetic interference
Electromagnetic interference (EMI) means disturbance to the functioning of an electrical device caused by an electrical field. The occurrence of EMI is difficult to establish or deny with certainty after the event. EMI occurs when unwanted currents, generated by another source of current or current interference, start flowing in an electrical circuit. Consequently, the occurrence of EMI has two prerequisites: (1) there must be two electrical circuits in proximity to one another and (2) there must a source of current with a relative large capacity relative to the circuit that is disrupted. In the context of a railway system, the current supplied for powering trains is a typical possible source of current that can cause a disturbance to safety systems and the ATB.

EMI can only occur if large-capacity alternating electric fields are present. Based on an estimation of the train running schedules, there were no requests for any unusually large currents shortly before the collision. Moreover, any currents would flow towards the substation (supply point for the overhead wires). In the case of most trains, the direction of the flow would be away from the site of the collision.

The Dutch Safety Board distinguishes three possibilities in which interference could have resulted in unsafe situations in this case:

- disruption of the ATB code;
- wrongly allowing a route section to be set;
- induction of a current resulting in a signal lamp wrongly lighting up.

The Dutch Safety Board does not consider any of these possibilities probable, as explained below. EMI as a cause of the collision can consequently be deemed improbable.

Disruption of the ATB code
An induced current could disrupt the ATB code of a train, resulting in the train wrongly receiving a route section permission in the cab signals. However, this would have been registered in the train event recorder data, which is not the case.

Wrongly allowing a route to be set
To set a route for a train, a number of safety conditions must first be met. For example, all switches must be set and locked in the correct positions and no other trains may be on the route in question.

153 According to the Train Event Recorder of both trains.

If these conditions are satisfied, signal aspects other than red may be displayed. In theory, EMI could wrongly influence one of these conditions (e.g. change the position of a relay), resulting in wrongly setting a route. Train traffic control log files demonstrate, however, that there was no attempt to set a route.

Induction of a current in a signal lamp cable, resulting in the lamp righting up
The functional test of the protection system showed that there had been no short circuit on the signal lamp cable. If there had been a short circuit, the lamp could only have lit up if a current had been induced on the cable linking the signal lamp with the relay for the route setting protection system.

Given that the cables of the red, yellow and green signal lamp run in parallel, one would assume that all three lamps (as well as those in the adjacent signals) would light up. Moreover, in order to have observed a yellow signal, the red lamp would also need to have been extinguished. In view of the design of the protection system, the Dutch Safety Board deems this improbable.

Possible explanations
The driver of the sprinter very probably made an error in his observation of the signal. There are two conceivable explanations for this:

The driver mistakenly observed a yellow signal intended for another train
At the moment the sprinter departed from Amsterdam Central Station, the yellow signal 606 indicated that the following signal (494) displayed red at that moment. The driver expected that he would have to stop. When the driver subsequently saw for the first time the row of signals that included signal 494, for several seconds the situation arose as illustrated in Figure 1.

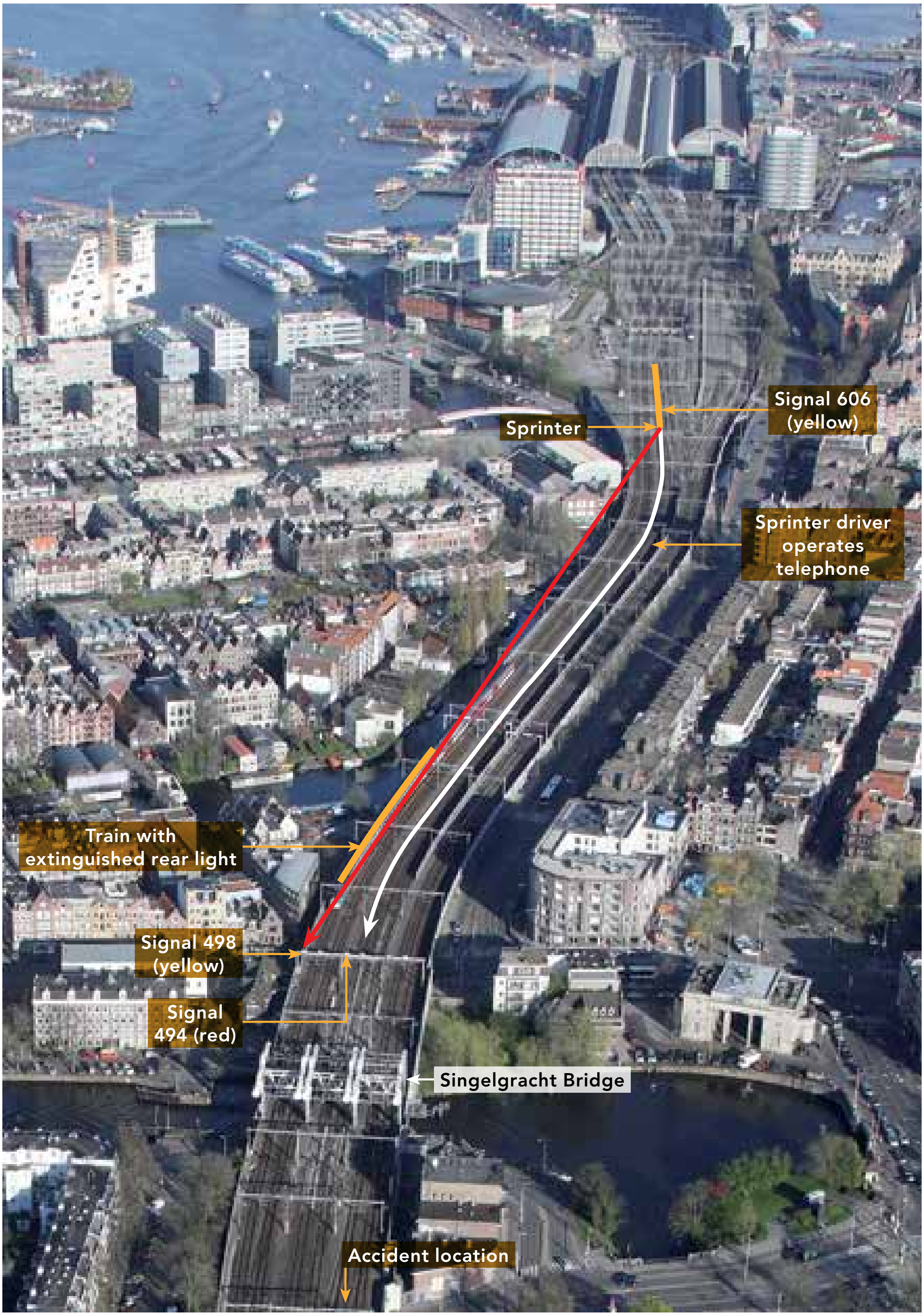


Figure 1: At the moment that the six signals before the Singelgracht Bridge first came into the view of the driver of the sprinter, signal 498 (intended for the train with the extinguished rear light) displayed yellow for a short time. However, as this signal is visible to the left of this train, the impression could have arisen at that point that the signal was intended for the track on which the sprinter was running. Photograph: KLPD.

The train with the extinguished rear light was in front of this row of signals for a short time. The signal for this train displayed yellow at that moment (signal 498). This signal is suspended above the track to the *right* as it supposed to be and as one would expect. However, owing to the S-curve of the tracks and the position of the driver of the sprinter at that moment, the signal was observed as being to the *left* of this train. The S-curve distorted the visual impression. Consequently, the impression could have arisen that the yellow signal belonged to a track to the left of the train with the defective rear light - such as the track the sprinter was running on.

Unlike a yellow-coloured *road* traffic light, a yellow rail signal like this does not mean that that the light could change to red at any moment, but that only the next signal in fact is red. If the driver had seen signal 498 displaying yellow and had mistaken this for signal 494, the driver could then have assumed from that moment that he only needed to stop at the signal after signal 494, which was at that point 1,600 metres farther down the track. This represents a time span of more than two minutes in which the train would continue running and the driver would need to take no action except to stop at that signal.

Consequently, the driver may have felt free to report that only one rear light of the train in front of him was lit. Telephone network records reveal that the driver started a conference call at the end of the curve after signal 606 (see figure 1). The call was preceded by a number of actions linked to operating the telephone. This may mean that the driver first saw the signal displaying yellow and then decided to make the call. However, this cannot be stated with certainty.

The journey then proceeded as follows: the driver of the sprinter then apparently drove on to signal 494 while looking at the rear light of the train in front of him. A number of train drivers responded to the conference call the driver of the sprinter had started, but the driver of the sprinter has declared that he did not answer these telephone responses as he wanted to keep his attention focused on the signals.

Signal 498 then became visible again straight ahead of the track of the sprinter. This signal had since turned red because the train with the extinguished rear light had passed the signal. This red signal was prominently visible but had no relevance for the driver of the sprinter as from the driver's location at that point it was clear that the signal did not belong to the track he was to drive on.

Signal 494 (also red) was also visible – although less well so – and farther to the left. This signal only became clearly visible when the sprinter was at the start of the second portion of the S-curve. The S-curve and the fact that the driver was occupied with the rear light of the other train may explain why the driver did not notice that signal 494 was in fact red and not yellow. If a driver has already observed a particular signal displaying yellow, there would be little reason to look at the same signal again: after all, the driver has already taken note of the signal. As such, a single mistake on the part of the driver can also remain unnoticed later on.

This is how the driver could have made an error in his observation of the signal, after which the distraction of the extinguished rear light and the train drivers' responses to the call may have contributed to the driver's failure to notice the error subsequently.

The location of the signal after a curve may have been a factor in both the original error and the failure to notice the error.

The incorrect observation of the yellow signal in the distance is central to this possible explanation. Otheer distracting factors, such as the rear light, are subsequent results of the original incorrect observation. The telephone call can in that case not have caused the error, but it can certainly have contributed to the error not being noticed. From the point of view of the train driver, calling at the moment was a safe action and he called in order to correct a wrong situation. The train driver therefore went about his duties in a responsible fashion, although he had made an error.

The train driver did not see the signal at all because he was distracted
It is also conceivable that the train driver was so completely distracted by observing the rear light of the other train that he paid too little attention to the other important task at hand: observing the signals relevant to his own train. Consequently, it is possible that the driver did not consciously observe signal 494 at all or that he incorrectly recalled the signal as he saw it.

The fact that the train driver can nevertheless declare that the signal displayed yellow can be attributed to 'false memories', memories of events or details of events that did not actually take place. In the case of the driver of the sprinter, this may mean that the train driver invoked a memory that matches the situation as one would expect it to be, or that matches other information that the driver did receive. At the same time, it is possible that the recollection of the last signal the driver consciously observed (signal 606, which was yellow) 'flashed out' the (forgotten) observation of signal 494. This may explain why the train driver believes he remembers seeing a yellow signal (during the journey and subsequently) while the signal was red.

APPENDIX 13: INJURY SCALES

At the request of the Dutch Safety Board, occupants from both trains described their injuries. These descriptions of individual injuries have been coded on the basis of two commonly used injury scales[154]: The Abbreviated Injury Scale (AIS) and the related Injury Severity Score (ISS) as applied in investigations into collision safety, transport accidents and aviation incidents.

Abbreviated Injury Scale (AIS)
AIS was developed within the discipline of traumatology in order to ensure that all emergency services at the scene of an accident classify traumas in the same way. The AIS is based on ten physical regions.

- Head
- Neck
- Face
- Chest
- Abdomen
- Spine
- Upper extremities (arms)[155]
- Lower extremities (legs, including skeletal parts of the pelvis)
- External or thermal injuries (injuries limited to the skin; such injuries are also often classified under one of the other regions, as is the case in this investigation)
- Other injuries

The system also distinguishes between seven types of tissue in order to allow for more detailed descriptions for each region, if necessary:

- Entire region (including the skin)
- Arteries
- Nerves
- Internal organs
- Muscles, tendons and ligaments
- Joints
- Skeleton

154 Sources: http://en.wikipedia.org/wiki/Injury_Severity_Score; http://www.aaam1.org/ais/; http://www.surgicalcriticalcare.net/Resources/injury_severity_scoring.pdf; Reurings, M.C.B., 2010. Ernstig verkeersgewonden in Nederland in 1993-2008: in het ziekenhuis opgenomen verkeersslachtoffers met een MAIS-score van ten minste 2. SWOV-rapport R-2010-15. SWOV Institute for Road Safety Research in the Netherlands - Leidschendam.

155 Also referred to a 'limbs' in the literature.

The information made available as a part of this investigation is not based on medical-pathological classifications. For this reason, the tissue types outlined above have not been applied in this investigation.

AIS distinguishes between six different injury levels, which are applied per body region:

- AIS 0 = No injuries
- AIS 1 = Minor (such as a contusion, abrasion or cut)
- AIS 2 = Moderate (such as a broken nose, arm, leg or rib)
- AIS 3 = Serious but non-life threatening (such as a crushed foot)
- AIS 4 = Severe (such as nerve damage resulting in significant functional decline)
- AIS 5 = Critical (such as a broken neck or life-threatening internal injuries)
- AIS 6 = Unsurvivable (such as decapitation)

The field of traumatology applies lists of disorders for each of the AIS regions, tissue types and injury levels, which are described in medical-pathological terms.

Injury Severity Score (ISS)
ISS was developed by the automotive industry in an effort to gain insight into the overall significance of injuries and required treatments for those who sustain multiple injuries (multi-trauma) during an accident.

Despite being based on AIS, ISS regroups the ten body regions into a total of six.

- Head/neck (including cervical vertebrae C1-C7; the neck is also classified separately)
- Face
- Chest (including the thoracic vertebrae - T1-T12)
- Abdomen (including the soft tissue around the hips and lumbar vertebrae - L1-L5)
- Extremities (arms and legs including the skeletal parts of the pelvis, the sacrum and coccyx)
- External or thermal injuries (injuries limited to the skin; such injuries are also often classified under one of the other regions, as is the case in this investigation).

This report applies the six ISS body regions. Passengers sustained multi-traumas. Furthermore, the more global ISS classification is more suited to the available injury information.

The ISS scores are calculated by squaring the AIS scores of the three most severe injuries to a specific body region, and subsequently adding up the results. The ISS score thus ranges from 1 to 75. If a person dies as a result of the accident, he/she is allocated the maximum score of 'ISS 75'.

This investigation distinguishes between minor and serious injuries. Minor injuries include injuries that heal quickly and do not affect or have a limited effect on the lives of the individuals involved, such as bruising, bleeding noses or grazes (injuries described by the parties involved, classified as AIS 1 and ISS 1-3 for the purpose of this investigation).

Serious injuries include injuries that require treatment, such as fractures and internal bleeding (injuries described by the parties involved, classified as AIS ≥ 2 and ISS ≥ 4 for the purpose of this investigation).

APPENDIX 14: INJURY, CAUSE OF INJURTY AND WHEREABOUTS IN THE TRAIN

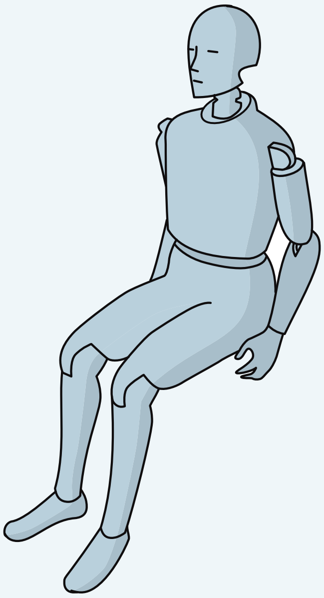
The investigation report includes a number of overviews of reported injuries of which are known to the Dutch Safety Board. This appendix contains more detailed information on the following aspects:

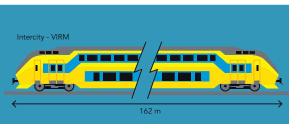
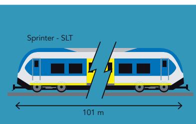
- an overview of the described injuries per body region;
- an overview of the type of seating or standing place where the passengers were located at the time of the collision in relation to the reported injuries;

These overviews offer an indication of the nature and severity[156] of the injuries sustained during the train collision. This indication allowed us to determine which risk factors in the two trains contributed to the occurrence of injuries and enabled attention to be drawn to the need for improving crashworthiness in respect of occupants, especially the train's interior.

This information is not suited to further quantitative or statistical analysis of the injuries. For example, it is unclear whether all passengers received a questionnaire. It is also unclear whether those that did not respond to the questionnaire sustained injuries. Furthermore, it proved impossible to determine the exact location of most passengers at the time of the collision.

156 Minor injuries include injuries that heal quickly and do not affect or have a limited effect on the lives of the individuals involved, such as bruising, bleeding noses or grazes (injuries described by the parties involved, classified as AIS 1 and ISS 1-3 for the purpose of this investigation). Serious injuries include injuries that require treatment, such as fractures and internal bleeding (injuries described by the parties involved, classified as AIS ≥ 2 and ISS ≥ 4 for the purpose of this investigation).



				
	Minor	Serious	Minor	Serious
Head/neck	8	2	17	6
Face	35	0	33	2
Chest	19	3	23	4
Addomen	1	2	0	0
Limbs (arms and legs)	66	3	56	8
Total	**129**	**10**	**129**	**20**
	139 (93 injured)		149 (96 injured)	

A single occupant may have sustained multiple injuries. As a result, the total number of described injuries exceeds the number of injured occupants. The injuries of the passenger who died have been classified under 'serious'.

Table 1: Number and severity of the described injuries by body region

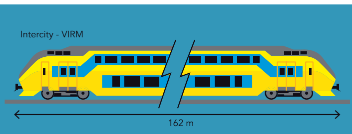
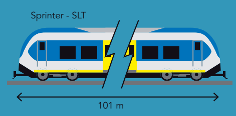
						
	No Injury	Minor	Serious	No Injury	Minor	Serious
Seated facing forward, seats						
Across from one another	9	38	5	1	34	3
Behind one another	1	24	2	0	6	4
Unknown/other	1	1	0	0	1	0
Seated facing backwards, seats						
Across from one another	13	9	1	7	17	0
Behind one another	9	1	0	11	0	0
Unknown/other	1	1	0	0	0	0
Seated in a lateral position						
Folding seat (lateral)	0	2	0	4	15	4
Other						
Seated, direction unknown	0	3	1	0	1	0
Standing	1	3	0	2	7	3
Driver's compartment	0	1	1	0	1	0
Total	**35**	**83**	**10**	**25**	**82**	**14**

Table 2: Described seating or standing place related to the injury.

APPENDIX 15: COLLISION SIMULATION

Both trains' movements shortly before and during the collision were reconstructed as accurately as possible. The following four steps can be distinguished:

- The deformations to both trains were analysed to determine the movement of the front of the two trains in relation to one another and the movements of the individual train coaches;
- The black box data were then analysed to determine at which speed the two trains approached the site of the collision, the extent to which they had braked before the actual collision and the speed at which they collided.
- An impulse calculation was then carried out in order to estimate the two trains' total change of velocity as a result of the collision;
- Finally, a computer simulation was conducted to analyse the movements of each coach.

Interpreting the photographs of the damage

Damage photos were analysed to determine the relative movements of the front of the two trains and individual coaches during the collision. To this end, the deformations to the front of both trains were recorded by means of a 3D laser scan (see image below). In addition, the most important coach deformations were manually measured.

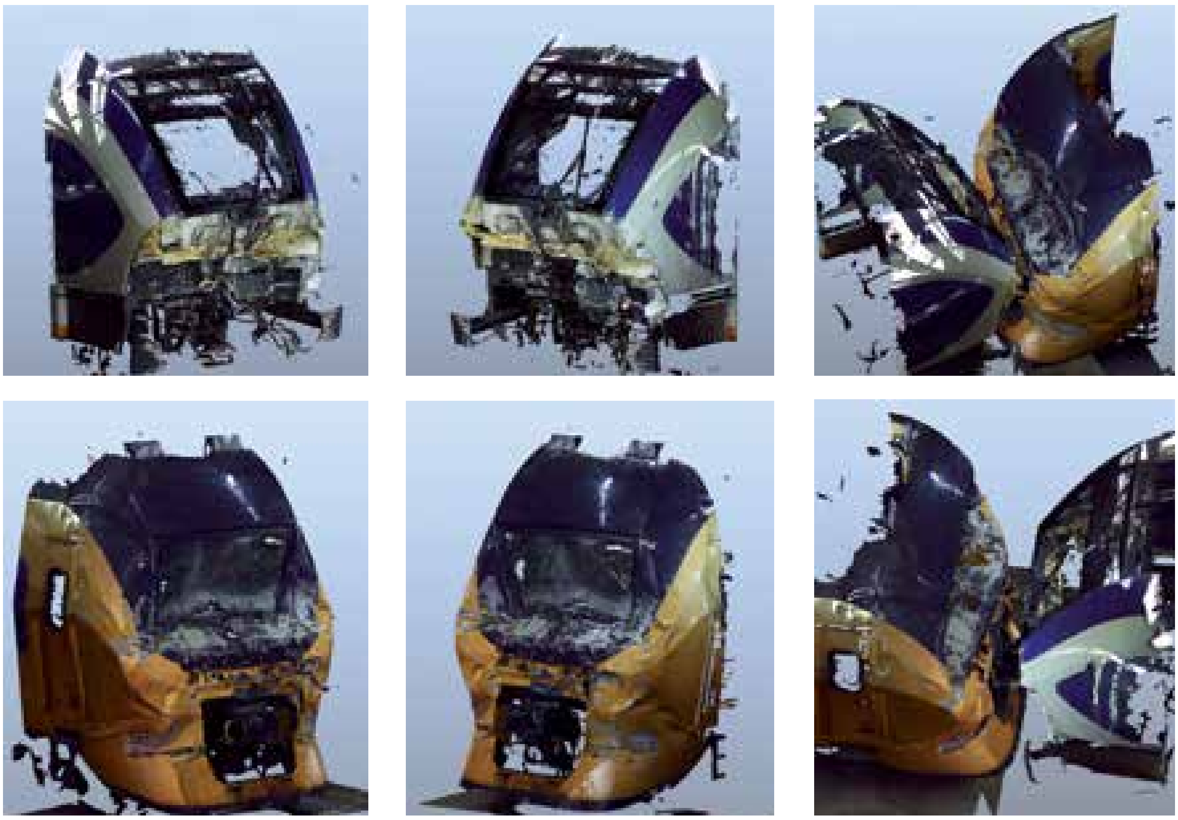


Figure 1: Laser scan images of the damage to both trains

Sprinter riding up over the intercity train
The front of the intercity train was damaged by various sprinter components. A comparison between the height of the damage sustained and the height of the relevant sprinter components showed that the front of the sprinter rode up over the front of the intercity train approximately 25 to 30 centimetres during the collision. Figure 2 specifies the most important height values.

The Dutch Safety Board studied the markings on the intercity train to determine at which height the following components of the front of the sprinter impacted the intercity.

- The lower section of the panel mounted on the front of the upper absorbers (A and E);
- The bottom of the anti-climber plates mounted on the front of the lower crash absorbers (C and D);
- The (mid-section of a) connector (B).

These height values were measured from the top of the rails and are expressed in metres.

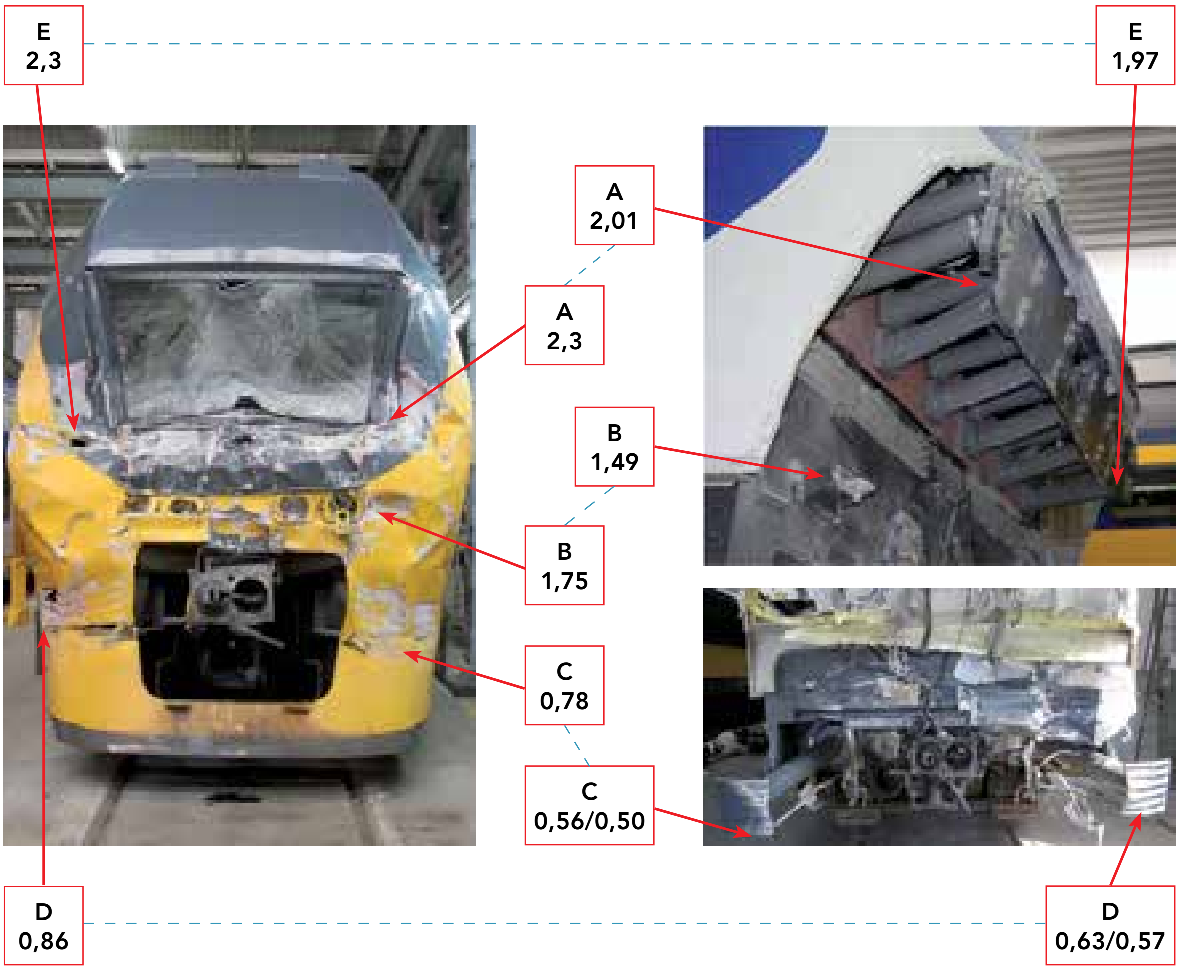


Figure 2: Comparison between the respective heights of sprinter components and intercity train markings. Source: Dutch Safety Board

To illustrate the difference in height, the photograph below shows the front of the two trains with the trains in their final position.

Figure 3: Damage to the sprinter and intercity train at the collision site. Source: Dutch Safety Board.

Collisions between individual intercity coaches

Analysis of the damage to the extremities of the intercity coaches showed that the coaches collided with one another after the couplings had collapsed. Figure 4 shows the type of damage to the coach extremities. All six intercity coaches suffered this type of damage.

Figure 4: Damage to the intercity coaches. Source: Dutch Safety Board.

Analysis of black box data

Both trains were equipped with a Train Event Recorder (*Automatische Rit Registratie*, ARR). This device registers various values at intervals of approximately one second. This includes aspects such as the position of the control instruments (including the traction or brake handle), the ATB code the train receives from the railway infrastructure and the train's speed. Due to the fact that certain information, such as the ATB codes, is also registered in the traffic control systems, the ARR data from both trains could be synchronised.

According to the ARR registrations, the intercity train approached the site of the accident at a speed of approximately 54 km/hr while the sprinter was travelling at a speed of around 43 km/hr. These registrations also show that the drivers of both trains braked vigorously shortly before the collision; this lasted approximately eight seconds in the case of the intercity train, and four seconds in the case of the sprinter.

The trains' precise speed at the start of the actual collision could not be determined on the basis of the ARR registrations. This is partly due to the fact that there is a slight delay between the actual train speed and its registration, while there was no way of determining the exact duration of this period. In order to provide some indication of the estimated collision speeds, the probable minimum/maximum duration of this period and deceleration of the trains during this time (minimum/maximum) was determined on the basis of various technical considerations.[157] Based on the recorded speed development, investigators were able to deduce that the intercity train was probably running at a speed of between 22 and 34 km/hr at the start of the collision, while the sprinter was probably running at a speed of between 20 and 25 km/hr. In other words: the total difference in velocity at the moment of the collision was probably between 38 and 58 km/hr.

Impulse calculation
The ARR systems are not designed to accurately register the development of train speed *during* a collision. In this case, it even proved impossible to determine the trains' speeds immediately after the collision on the basis of the ARR data. However, collision mechanics do enable us to estimate the changes in the two trains' velocities as a result of the collision.

$$S1 = -S2 = (1+k) \cdot \frac{m_1 \cdot m_2}{m_1 + m_2} \cdot v_r \text{ [1] en } \Delta v = \frac{S}{m} \text{ [2]}$$

According to the law of impulse (see comparison 1), the impact (S_1 and S_2) exerted by the two trains during the collision depends on the size of their respective masses (m^1 and m^2) and the ratio between the two, the relative difference in velocity (v_r) between the two trains and the elasticity (k) of the collision. The factor of elasticity (k) indicates the extent to which the deformations occurring during the first phase of the collision were either plastic (permanent) or elastic (in which the zone returns to its original form during the second phase of the collision). The impact (S) (see comparison 2) determines the changes to the two trains' velocities (Δv) as a result of the collision.

Calculations were based on the assumption that the intercity had a mass of 350 tonnes, while the sprinter had a mass of 175 tonnes; the elasticity was estimated at between 5% and 15%. Based on these values and the above collision speeds, the impulse calculation leads us to conclude that the intercity train probably underwent a change in velocity of 12 to 22 km/hr as a result of the collision, while the sprinter underwent a change in velocity of between 25 to 43 km/hr.

157 Based on the information available, it has been determined that the brake retardation in both trains prior to the collision was between 1.0 en 1.5 m/s^2. A speed registration lag of 1.0 to 1.5 seconds in the case of the sprinter and of 1.75 to 3 seconds in the case of the intercity train have been assumed based on what is known about the technical design of both Train Event Recording (ARR) systems.

This means the change in velocity experienced by the sprinter was approximately twice as great as the change experienced by the intercity train (approximately 34 ± 9 km/hour and 17± 5 km/hour, respectively). This information also leads us to conclude that immediately after the collision the intercity was still travelling forward at a speed of approximately 10 ± 1 km/hour while the sprinter was moving backwards at a speed of 15 ± 5 km/hour.

Computer simulation

The impulse calculation can only be applied to calculate the trains' overall change of velocity, as it regards the two trains as a 'one whole'. In reality, the two trains consisted of multiple interlinked coaches that were able to move independently during the collision. As a result, the abruptness with which the velocity of each coach changed (decelerated) could vary. As the images of the damage show, this actually was the case and probably affected the intercity train more than the sprinter. As mentioned earlier, the couplers between the coaches of the intercity train collapsed, and the coaches subsequently collided with each other. In order to assess the effect this would have had on the mechanical loads to which the occupants were subjected, the movement trajectory of the coaches was analysed in further detail by means of a computer simulation. At the behest of the Dutch Safety Board, these calculations were conducted by TNO Automotive Safety Solutions (TASS) using Madymo simulation software158,159. The computer simulation is described in a separate report. The section below provides a brief summary of the models/underlying basic principles and calculation results.

Models/basic principles

The mathematical model regards the coaches as individual vehicles, and models the bogies on each coach as separate bodies. The coach model is also based on the assumption of deformable zones on the front of the trains, the couplers between individual coaches and the actual deformations on the intercity coaches. As regards the rigidity of the deformable zones, the model applies values designed to ensure that the calculated deformations reflect actual coach deformation as closely as possible.

It is assumed that the relevant section of track was straight and horizontal. The model is also based on the assumption that, at the start of the collision, the intercity train was travelling at a speed of 28 km/hr and the sprinter at a speed of 20 km/hr (a collision speed of 48 km/hr). The simulation was conducted over a period of 1,000 milliseconds, commencing at the start of the collision.

158 Madymo is the international standard for vehicle occupant safety analysis and optimisation software.
159 The report is available as a digital appendix to this report on our website: www.safetyboard.nl

Figure 5 shows the coach models used in the simulation (the upper image represents the intercity train while the lower represents the sprinter).

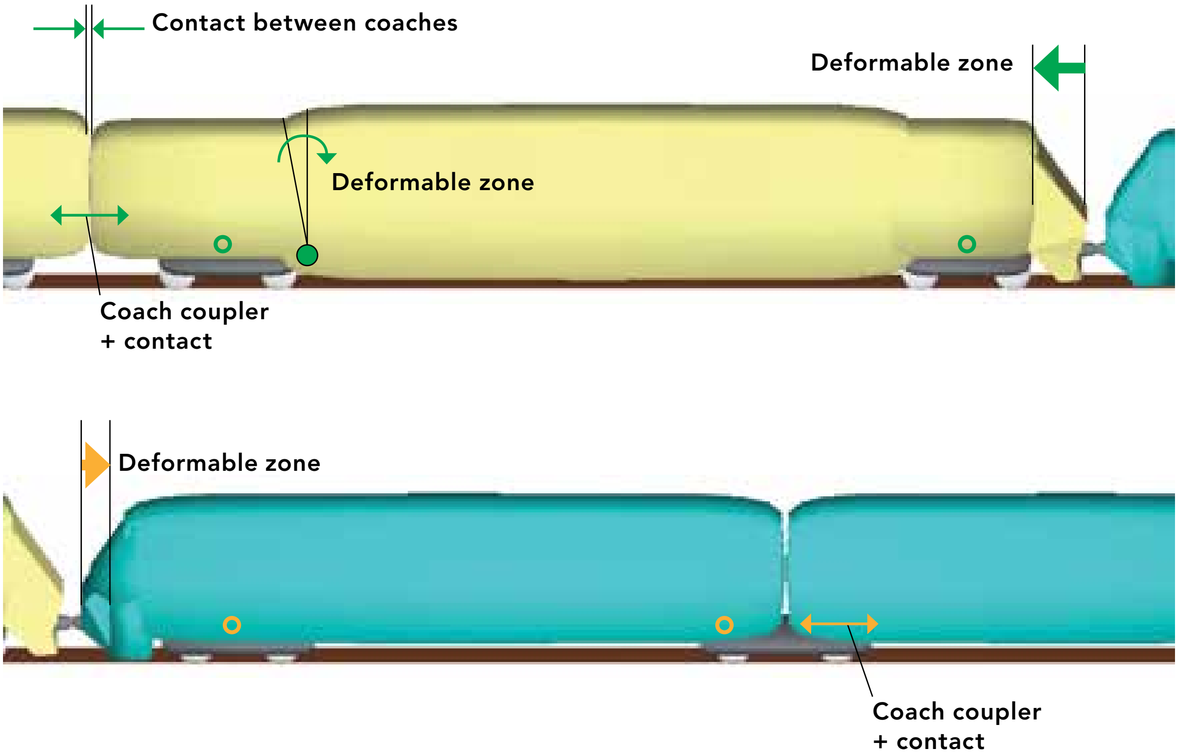


Figure 5: Coach models used in the simulation.

Simulation results

The result of the simulation, described in further detail in the TNO-TASS report referred to above, has been summarised in the graphs below.

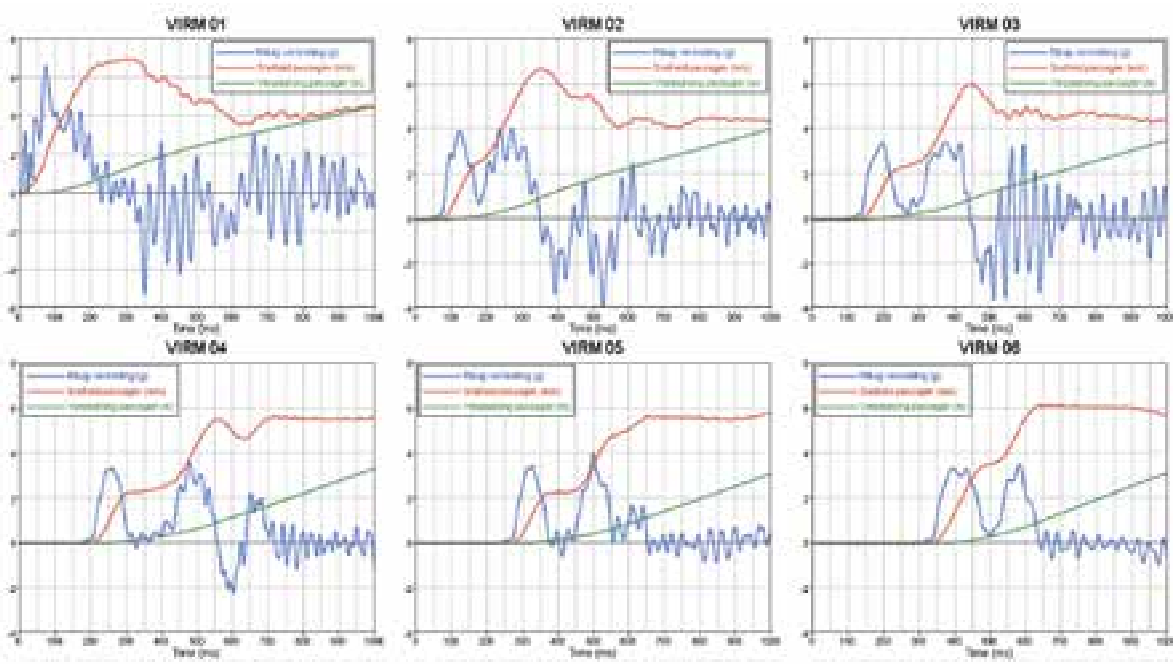


Figure 6: The movement trajectory of the six coaches of the intercity train.

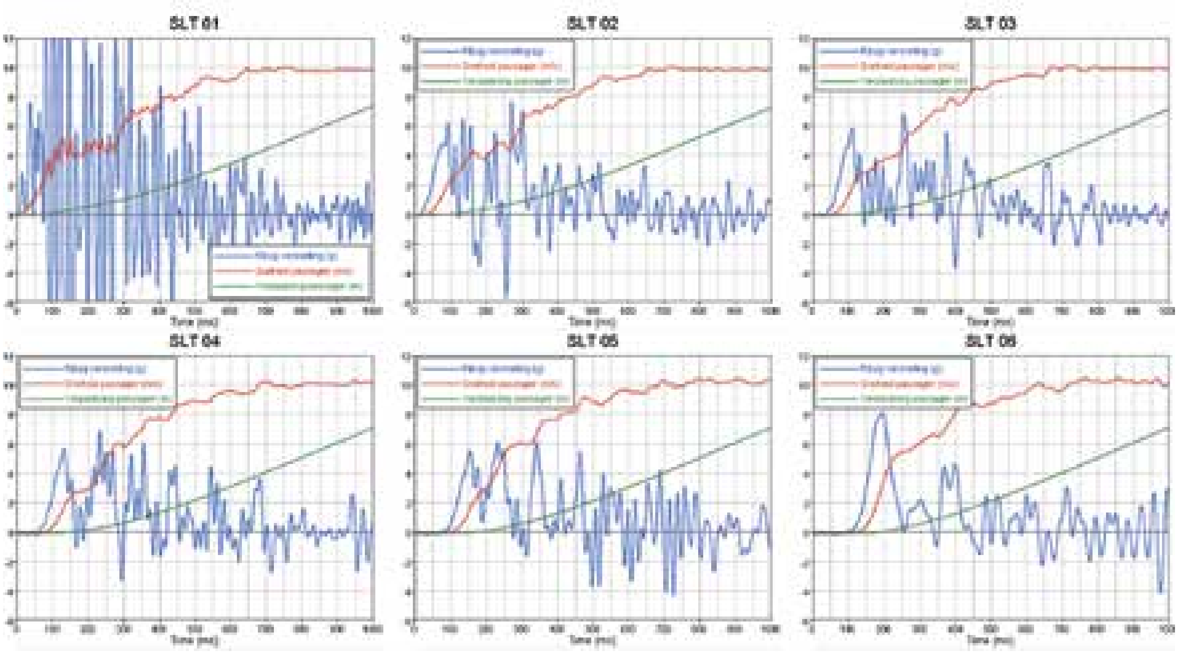


Figure 7: The movement trajectory of the six coaches of the sprinter.

Figure 8 provides an indication of the occupants' potential speeds in comparison with the train during the collision, depending on the distance over which they could move freely within the train.

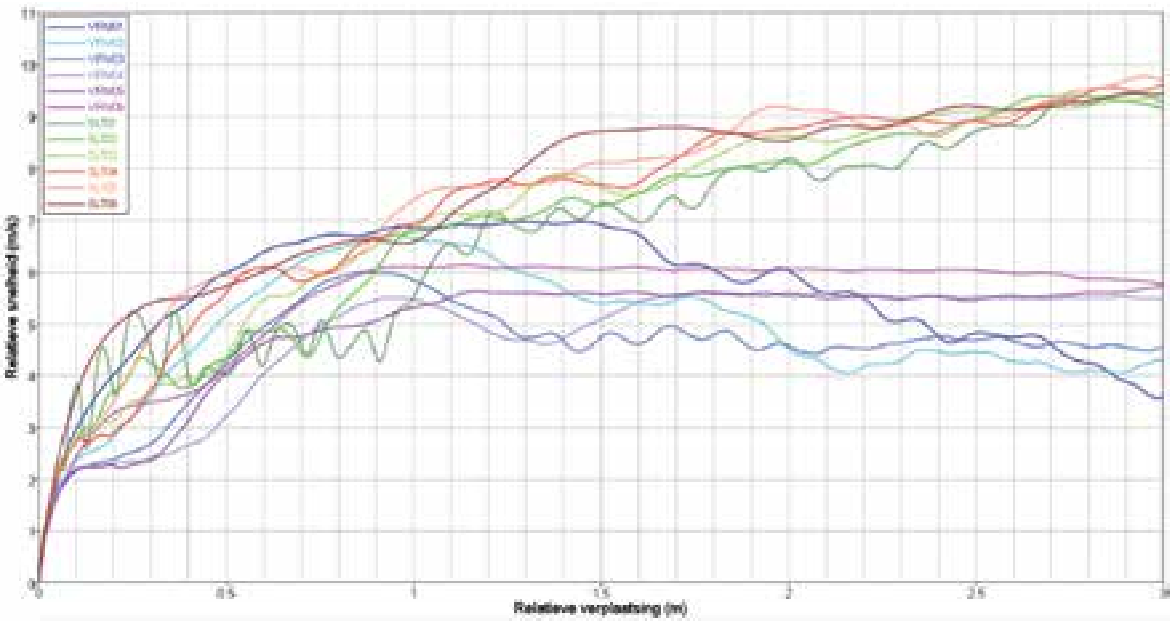


Figure 8: The movement trajectory by coach of a (non-fixated) virtual occupant for each coach.

APPENDIX 16: LITERATURE CONSULTED

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