DUTCH
SAFETY BOARD

Train derailment Hilversum

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Dutch Safety Board

The aim in the Netherlands is to limit the risk of accidents and incidents as much as possible. If accidents or near accidents nevertheless occur, a thorough investigation into the causes, irrespective of who are to blame, 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 independence with respect to authorities and businesses. In some cases the Dutch Safety Board is required by law to conduct an investigation.

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NB: This report is published in the Dutch and English languages. If there is a difference in interpretation between the Dutch and English versions, the Dutch text will prevail.

CONTENT

ABBREVIATIONS AND DEFINITIONS

Technical terms with respect to switches	
Stock rail	These terms regarding the switch construction are explained in appendix B.1 (with figures).
Locking rod	
Detection rod	
Ekos-V rollers	
Slide chairs	
Switch mechanism	
Switch blade	
Hitting the (open) blade or flange-back contact	These terms regarding the operation of a switch are explained in appendix B.2 (with figures).
Flange-back clearance	
Free wheel clearance	
Running through (a run-through event)	
Release mechanism	
Track gauge	

Other definitions and abbreviations	
Management concession	Concession granted by the Minister of Infrastructure and the Environment to ProRail for the management of the Dutch railway network.
Ring	Component in the release mechanism of the EBI switch that is meant to break in the case of a run-through event.
EBI switch	Type of point machine (installed in switch 3B - the switch at which the train derailed).
ERA	European Railway Agency.
FMECA	Failure Modes Effects & Criticality Analysis (method for risk analysis).
ILT	Human Environment and Transport Inspectorate (Inspectie Leefomgeving en Transport).
kN	Kilo Newton: unity of force.
Walking visual inspection	Visual inspection of the railway track whereby the track is examined from the inspection path (next to the track) while walking.
NSE point machine	Type of point machine.

Other definitions and abbreviations	
OPC	Output process maintenance contract: type of contract in which the contractor has a best efforts obligation; the railway infrastructure manager prescribes the maintenance work that needs to be carried out.
Crossover switch	Set of two switches, between parallel tracks, that have the function to guide trains from the one railway track to the other (crossing over).
PGO	Performance-based maintenance contract: type of contract in which the contractor has a performance obligation; the railway infrastructure manager lays down the requirements with which the railway must comply instead of prescribing the maintenance work.
TSI	Technical Specifications on Interoperability (European directive).
Video inspection	Inspection of the railway track whereby video recordings of the track are made using a video inspection train.

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CONSIDERATION

On 15 January 2014, an intercity train derailed shortly following its departure from Hilversum station. The train passed a set of points (switch) that during the passage of the train shifted to a different position, leading to the derailment. Derailments of this kind are among the most serious conceivable safety breakdowns in rail transport, since they can result in a major accident. The derailment was caused by a defect in the switch. Both the quality of the switch part that experienced the defect and the general maintenance of the switch contributed to the occurrence of the derailment. In this consideration, the Safety Board above all addresses the maintenance of the railway infrastructure and the manner in which the parties involved have fulfilled their maintenance tasks.

The Dutch railway infrastructure is managed by ProRail. ProRail outsources the maintenance of that infrastructure to contractors. With regard to this process several developments have taken place over the past few years. Due to the increased pressure from a society that is demanding improved railway performance, more strongly than in the past, maintenance focuses on preventing disruptions. This is also reflected in the new management concession from the Minister of Infrastructure and the Environment to be awarded to ProRail (2015 - 2025) and the long-term railway policy in which the government aims above all at reducing disruptions to train services and increasing passenger satisfaction. In the past, maintaining the sound technical condition of the infrastructure was an independent objective in itself, but over the past few years the objective has shifted increasingly towards ensuring optimum availability of the railway infrastructure. A further development is that in the tendering process for maintenance, ProRail has stimulated more market competition, in order to make maintenance more efficient and more innovative. This tendering process itself has led to a shift in the distribution of tasks between ProRail and the maintenance contractors. ProRail now expects the contractors to use their own expertise in determining what maintenance is necessary. As a consequence, ProRail is increasingly opting to provide outline guidance for railway infrastructure maintenance and to deploy financial stimuli in order to achieve a specified railway infrastructure condition.

The developments outlined above aim to improve the quality of rail transport and to reduce the cost of train travel. These two objectives are defensible and well worth pursuing, as long as they do not take place at the expense of safety. However, considering the train derailment in Hilversum and the contribution of the railway infrastructure maintenance policy to that derailment, the Safety Board views a source of concern. There is a risk that railway infrastructure maintenance is becoming too unilaterally focused on preventing train service disruptions, while ignoring issues that are not so relevant to availability of track, but are to safety. The parties may gradually sail closer to the wind, thereby unintentionally and unnoticed, compromising too much on safety. Only when things go wrong – as in the Hilversum derailment – it becomes clear that a threshold has been passed.

The investigation into the train derailment revealed that a switch suffered serious wear, without this leading to disruptions. Because the switch did not indicate the presence of a problem, the maintenance contractor took insufficient notice of the wear during maintenance work. Such action was not required by the maintenance regulations. ProRail had limited insight into the execution and result of the maintenance work, as a consequence of which the technical deterioration of the switch also remained unnoticed by ProRail, until the moment at which the derailment took place.

Maintenance contractors have the tendency to give priority to those issues on which they can be directly called to account. In the absence of clear safety standards, and with lacking supervision by ProRail, there is no stimulus to pay sufficient attention to specific switch parts. The opposite is the case for issues that are relevant to keeping the railway infrastructure disruption-free. The requirements for the functionality of the railway infrastructure (disruptions, repair times) imposed by ProRail on the contractor are concrete as well as accountable. Any violations are guaranteed to result in a penalty. To prevent attention for safety becoming overlooked as a consequence, it is vital to employ clear safety standards and to monitor the compliance with those standards. This is a condition that applies irrespective of the form of the maintenance contract, whether it relates to the maintenance work to be carried out or to the result of that work. In the judgement of the Safety Board, current maintenance execution practice does not yet fulfil this condition. Two investigation reports recently published by the Human Environment and Transport Inspectorate, concerning railway infrastructure maintenance, underline the concerns of the Safety Board. The Board is of the opinion that ProRail needs to more firmly embed the safe condition of the railway infrastructure in its regulations for contractors. To be able to take corrective measures in good time, ProRail needs to know the condition of the railway infrastructure. This is inherent in the contract-awarding role and responsibility of the railway infrastructure manager, imposed by law. Nonetheless, the maintenance contractors need to correctly fulfil their task, within the freedom granted them.

In this connection, the State Secretary for Infrastructure and the Environment also has a task. In consultation with the railway infrastructure manager and the transport operators, the State Secretary is in the position to ensure that the objectives of availability, punctuality and safety remain in balance. From that point of view, the Safety Board believes that the State Secretary must emphatically consider the safe usability of the railway infrastructure, in the reassessment of the policy framework for railway safety currently taking place. Furthermore, the State Secretary must solidly embed this aspect in the management agreements with ProRail.

Furthermore, the Safety Board notes that also in other public services, the operational work in respect of management and maintenance is contracted out to market parties, on the basis of performance-based contracts. The train derailment in Hilversum teaches us that the related interests can gradually and unnoticed apply pressure on the management of safety risks. In that sense, the safety lessons drawn from this accident can also be relevant to other sectors.

SUMMARY

On 15 January 2014, a passenger train derailed at a switch just outside Hilversum station. After the first section of the train had travelled in a straight direction over the switch, the rear section of the train was suddenly directed onto the adjacent track, as a result of which the train derailed. A train travelling in the opposite direction on the adjacent track was successfully brought to a standstill approximately two hundred metres before reaching the derailment site, thereby avoiding a collision. As a consequence of the derailment, a number of passengers suffered minor injuries, while serious material damage was caused to the track infrastructure and the train. The Dutch Safety Board investigated this accident, partly on the basis of its potential seriousness.

When the train travelled over the switch, a part of the switch mechanism (point machine) broke. A technical investigation revealed that the part failed due to fatigue. The fatigue fracture arose because the part in question was in practice exposed to forces that were higher and more dynamic than those taken into account in the design. In addition, this part revealed finishing defects. These additional forces were caused by the fact that during train passages, the insides of the train wheels scraped against the switch blades.[1] This 'hitting' action caused the switch blade to oscillate, whereby additional forces were applied to the part, for which it was not designed. These additional forces eventually led to a fatigue fracture.

The hitting of the switch blade (known as flange-back contact) was caused by the poor maintenance condition of the switch. Various parts of the switch were so worn that they could no longer fulfil their function, namely supporting and guiding the switch blade. As a consequence, when shifting back and forth, the switch blade experienced such a degree of resistance that it remained too close to the rail. This in turn meant that the wheels of passing trains regularly scraped along the switch blade, while this was not supposed to happen. It became clear from the investigation that these flange-back contacts were not caused by the train traffic but by the state of maintenance of the infrastructure.

The wear to the switch did not occur overnight. Maintenance should have led to repair. This was not the case. The investigation revealed that ProRail did not see any safety risk in flange-back contacts and as a consequence did not consider it necessary to prevent such contacts. A further contributing factor was that over the past few years, no incidents or accidents in the Netherlands have occurred as a result of flange-back contacts. ProRail outsources the maintenance of the railway infrastructure to contractors. Maintenance is

1 The movable parts of a switch (set of points) that direct the train from one track to another are known as switch blades. A switch has two switch blades (a left-hand and a right-hand blade), which both shift to the left or right, as the points are switched. These blades are shifted by the point machine.

governed by contract regulations and provisions. The maintenance regulations imposed on contractors by ProRail were insufficient to prevent flange-back contacts.

The regulations demonstrated gaps which were not compensated for by suitable maintenance by the contractor. It is relevant in this connection to note that increasingly, maintenance is becoming focused on the objective of preventing train service disruptions. The wear to the switch parts did not result in any disruptions. The absence of such disruption problems meant that the contractor responsible for carrying out the maintenance was not alert to the deterioration of these parts, and failed to pay sufficient attention to this situation in its maintenance activities. This situation was exacerbated by the fact that six months prior to the train derailment, a change in maintenance contractor had taken place, whereby the maintenance condition of the switch in question was not explicitly discussed. The Dutch Safety Board observed that the supervision by ProRail had no corrective effect. ProRail above all supervised the execution of maintenance work 'on paper', and itself had no knowledge of the actual condition of the switch. As a consequence, a heavily-used switch had become unsafe, without this situation being observed and dealt with.

The scenario that emerged in Hilversum was not foreseen in advance by any of the parties involved. The manufacturer of the point machine (Bombardier) and ProRail followed different principles, in respect of the load on the point machine. In its design process, Bombardier assumed that the point machine would only be exposed to normal operating forces, while ProRail did not prevent the occurrence of additional forces. The investigation revealed that the discrepancies in operating principles were not identified in time, as a result of insufficient information exchange on these issues between Bombardier and ProRail.

A number of technical problems with point machines of this type occurred several years previously. These could have revealed the failure mechanism if the parties had operated a broader perspective on learning. In tackling the previous problems, Bombardier and ProRail restricted themselves to eliminating the direct causes. As a consequence, the risk of fatigue due to flange-back contact was not adequately dealt with, despite indications that such a risk could occur. Furthermore, insufficient lessons were learned from several previous train accidents. A scenario comparable to that in Hilversum occurred in a train derailment in 2007, in Grayrigg (England). If the knowledge of this serious accident had been utilised, it would have been known that the hitting of switch blades (flange-back contacts) even over a short period of time can massively reduce the lifetime of switch parts and as such represents a safety risk that needs to be managed.

The safe usability of a switch is the result of cooperation between several parties; in this case, Bombardier, ProRail and the maintenance contractors. The degree to which these parties succeed in correctly harmonising the various processes in the chain is decisive for the safety of the overall system. The derailment in Hilversum revealed that on these aspects, there is room for improvement in current practice.

Recommendations

On the basis of its investigations, the Dutch Safety Board has issued the following recommendations:

To ProRail

1. Organise railway maintenance in such a way that the safety risks are explicitly and demonstrably managed, irrespective of other interests (such as availability and costs). Develop stimuli for maintenance contracts that offer contractors maximum encouragement in actively promoting railway safety. Monitor to ensure that contractors actually carry out the necessary maintenance and that this maintenance has the desired result.
2. Ensure that relevant design, user and maintenance information on all railway infrastructure parts is available to the various chain partners. Also encourage active knowledge sharing on (near) accidents and innovative developments (both nationally and internationally).
3. Tighten up regulations governing the (design, laying and inspection/maintenance of) switches in such a way that flange-back contacts are effectively countered. Incorporate the tightened regulations as mandatory in the (current and future) contractual agreements with the companies involved.

To ProRail and the maintenance contractors

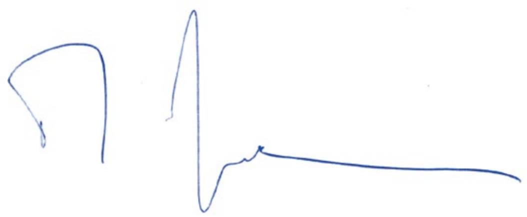
4. Together, ensure an up-to-date and complete picture of the technical condition of the railway infrastructure. Use this information for adequate management (asset management) whereby – besides monitoring the functionality and service life – safety is demonstrably guaranteed.
5. Make sure when transferring a maintenance contract, that all relevant information about the technical condition and maintenance history of the railway infrastructure in question is transferred fully and in an accessible manner to the future contractor.

To Bombardier

6. When supplying railway parts (such as the EBI switch point machine), provide users with clear, safety-related user specifications. Monitor to ensure that these requirements are met in practice, and warn users if this is not the case.

To the State Secretary for Infrastructure and the Environment

7. Make sure that the safe usability of the railway infrastructure is granted sufficient weight in relation to other interests (such as capacity and punctuality). Integrate this vision in the current rethink of the policy framework for railway safety, and bring about a situation whereby ProRail and the maintenance contractors are able to successfully act in accordance with it.



T.H.J. Joustra
Chairman, Dutch Safety Board

M. Visser
General Secretary

1 INTRODUCTION

1 INTRODUCTION

1.1 Background

On Wednesday 15 January 2014, a passenger train operated by NS Reizigers derailed upon departing Hilversum station in the direction of Naarden-Bussum. The train derailed at a switch. The accident and the situation after the event revealed that during the passage of the train, one of the switch blades had shifted. After the first section of the train had travelled in a straight direction, the rest of the train was directed onto the adjacent track. In rail transport, this is one of the most serious conceivable safety breakdowns. The material damage to the railway infrastructure was considerable. A train travelling in the opposite direction was able to halt just in time, thereby avoiding a collision.

1.2 Objective and investigation question

The aim of the investigation by the Dutch Safety Board is to assist the parties involved in learning from this incident. A further aim of the investigation is to independently inform the public. The investigation is focused on identifying the reasons why the parties concerned failed to guarantee the safe operation of the switch. The investigation will not only consider technical causes but also the organisation of processes, the intention of which is to ensure that a switch can be passed safely. These processes are closely related to one another. Also important for the investigation is to gain an insight into the way the responsible parties cooperate and influence one another.

The following two investigation questions have been formulated:

1. *What was the direct cause of the train derailment?*
2. *Why did the parties concerned whose task it was to guarantee that the switch could be passed safely fail to prevent the derailment?*

To be able to answer these questions, as much information as possible was gathered about the derailment and the underlying problem. This information was obtained by visiting the derailment site shortly following the accident, consulting documentation and questioning the relevant parties. The findings were assessed against an reference framework drawn up by the Dutch Safety Board. In this investigation, the reference concerned commissioning, cooperation in the chain and learning capacity. The reference framework employed is further explained in appendix G.

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1.3 Responsible parties

The train derailed on a heavily-used section of the railway network. To make such intensive use possible, the infrastructure must be managed.[2] The Railways Act specifies that the Minister of Infrastructure and the Environment is responsible for this task. This responsibility comprises the sound regulation of safety by means of legislation, the issuing of permits and supervision. The permit-issuing and supervision tasks are entrusted to the Human Environment and Transport Inspectorate (ILT).

On the basis of the Railways Act, the Minister granted a concession to ProRail for the management of the railway network. The current management concession is issued for the period 2005-2015. The management concession includes a duty of care. The essence of this obligation is that the responsibilities of ProRail include ensuring that 'the main railway network can be travelled safely and efficiently' and 'that the safety risks are analysed and sufficiently managed with suitable measures'. The next management concession (for the period 2015-2025) will also be awarded to ProRail.

ProRail has opted to outsource the actual maintenance on the railway infrastructure to contractors. Maintenance in the contract area of which Hilversum forms part was outsourced to Strukton Rail until 1 July 2013. Of the maintenance contractors approved by ProRail, Strukton Rail is responsible for maintenance of the largest proportion of the railway network. In the field of railway systems, this company operates internationally. From 1 July 2013 onwards, maintenance was tendered out to Asset Rail. Asset Rail is the railway maintenance contractor most recently approved by ProRail. It is a young, small organisation, that emerged from an initiative undertaken by Dura Vermeer, Arcadis and Imtech.

The switch in Hilversum was equipped with a point machine of the type EBI switch 2000 (hereinafter: EBI switch). The EBI switch is manufactured and supplied by Bombardier Transportation. Bombardier operates worldwide as a major multinational in the railway sector.

1.4 Investigations by other parties

In addition to the Dutch Safety Board, other parties carried out an investigation into the train derailment in Hilversum. ProRail investigated the technical causes of the accident, together with the analysis and management of risks in maintenance. The investigation by NS Reizigers focused on the question of whether the derailment in any way related to the train involved. The NS investigation revealed that this was not the case. The ILT above all investigated how the railway managers responded following the derailment. An investigation was also carried out into whether and if yes, what regulations are violated, and what lessons can be learned in respect of maintenance management. A further explanation of the results from the investigations by the other parties is contained in appendix F.

2 A further explanation of the management of the Dutch railway network is contained in appendix D.

1.5 Reading this document

This report describes the facts of the accident and explains the causes. Chapter 2 deals with the derailment and its direct cause. Chapter 3 contains an outline of the problem analysis, followed by an explanation of the underlying factors that played a role in the occurrence of the problem in chapter 4. Chapter 5 contains the conclusions to the investigation. These conclusions in turn led to recommendations that appear in chapter 6.

2 THE ACCIDENT

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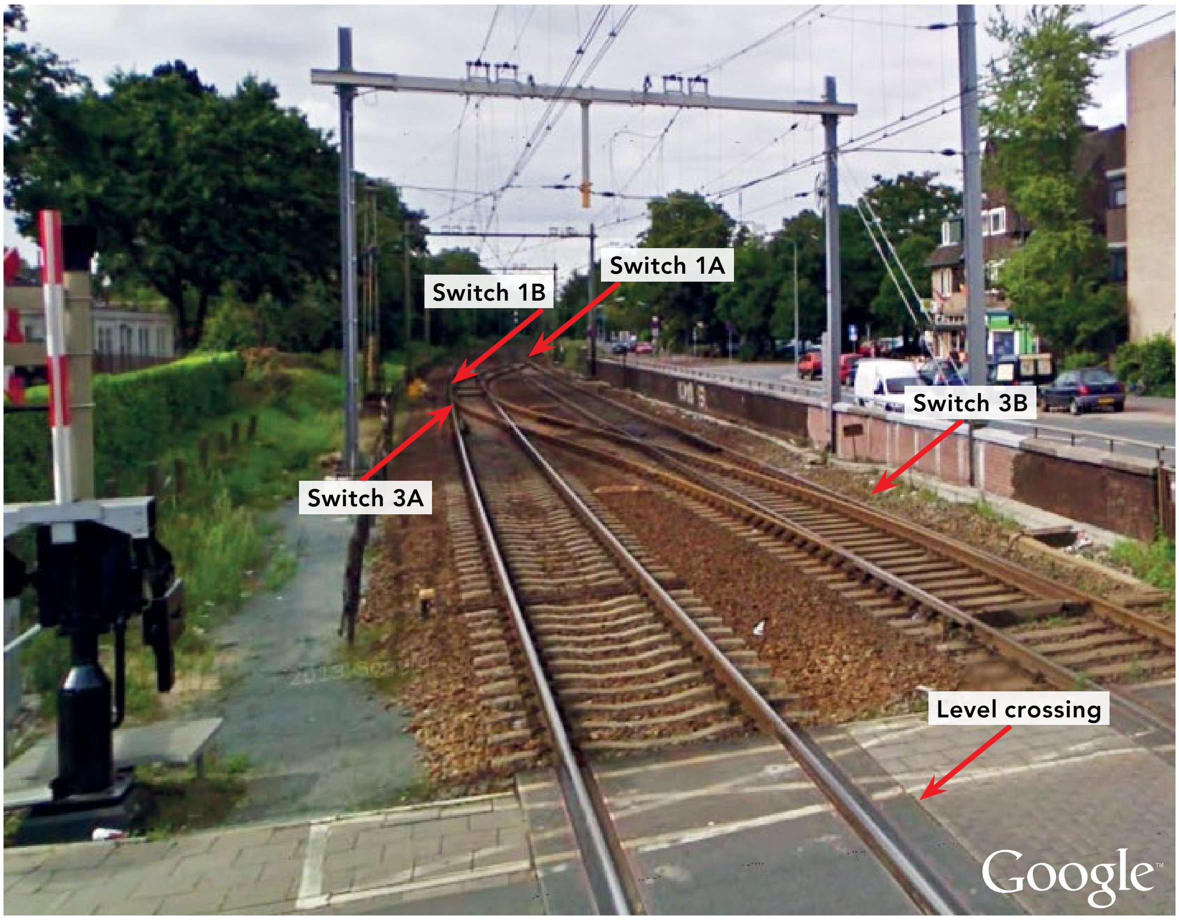
2 THE ACCIDENT

2.1 The derailment and its consequences

The train was travelling from Enschede to Schiphol. In addition to the driver and conductor, there were approximately 550 passengers on board of the train. After a short stop at Hilversum station, the train departed towards Naarden-Bussum at 15.53 hours. Approximately 300 metres outside the station, the train derailed at a switch, namely switch 3B.



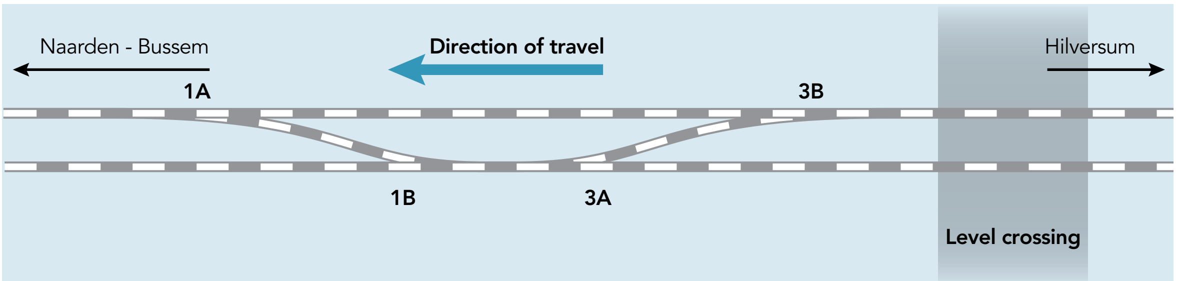


Figure 1: Location of the derailment with positioning of the two crossover switches. (Source: Google earth)

The switch is located immediately adjacent to a railway level crossing, as shown in figure 1. Each year, approximately 65,000 trains pass this switch, equivalent to approximately 175 trains per day. It is a heavily used section of track. Switch 3B is almost exclusively (more than 98% of train passages) passed in straight direction. On average, only three trains per day are directed to the adjacent track. The switch primarily has a function in redirecting the rail traffic.

In the part of the section of track in question, there are two sets of crossover switches (1A/B and 3A/B). After the first carriage of the train passed switch 3B travelling straight on, the rear section of the second carriage was directed from the right-hand track onto the left-hand track. The subsequent carriages of the train were then also directed to the left-hand track via switch 3B. The train continued on for more than two hundred metres, whereby the carriages were directed from the left-hand track back onto the right-hand track, via crossover switch 1A/B. In the final position, the front five carriages were on the right-hand track; the sixth carriage was on crossover switch 1A/B and the seventh carriage was still on the left-hand track (see the bottom illustration in figure 2).

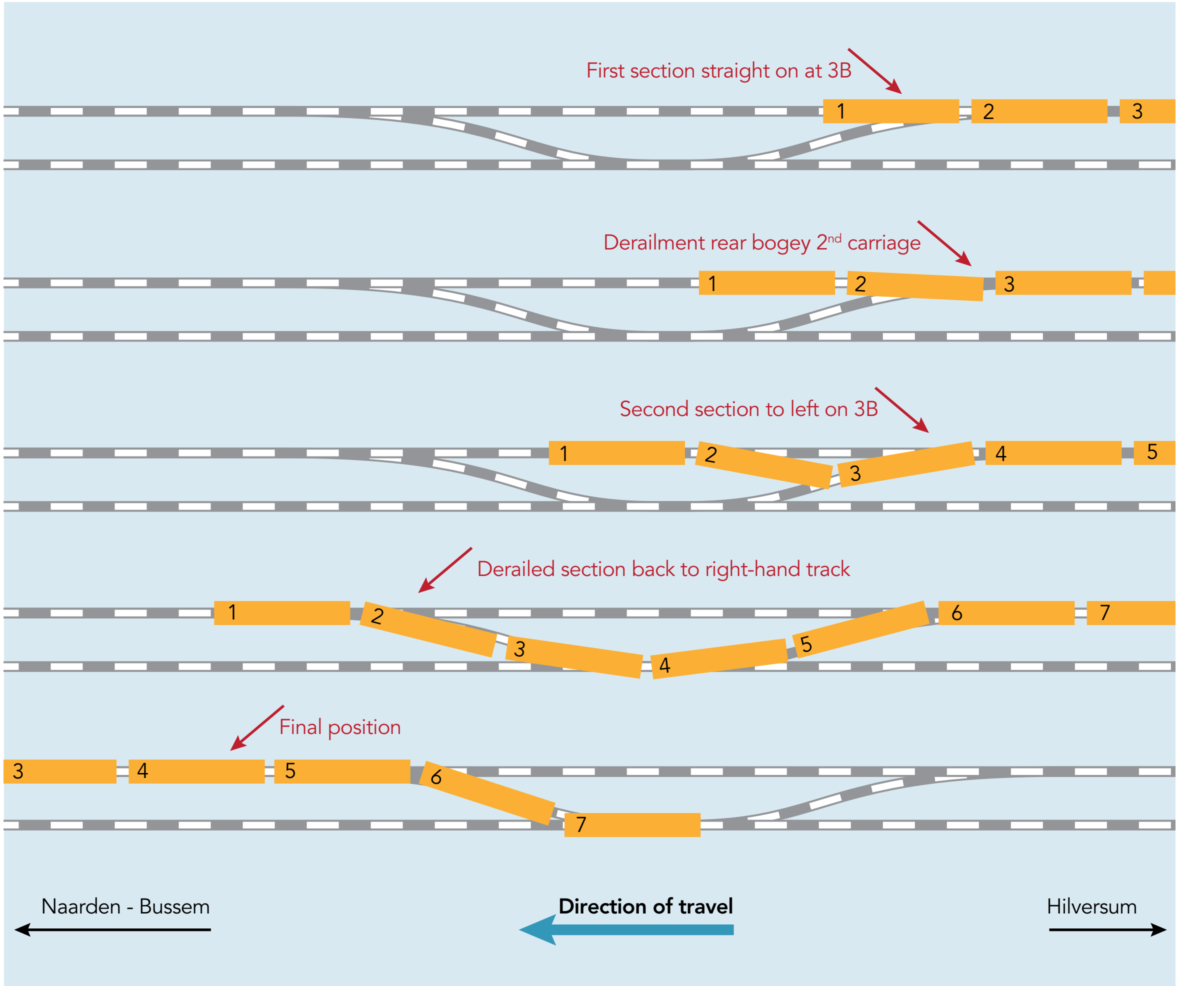


Figure 2: Top view of the course of movement of the carriages during the derailment.

The illustrated course of movement was derived from video images recorded by cameras at the level crossing, and from the consequential damage to the infrastructure and the rolling stock. In the final position, only the front bogie of the second carriage ended up 'alongside the rails' (see figure 3), but the damage to the wheel sets, rails and sleepers clearly showed that four other bogies temporarily had been derailed as well.

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Figure 3: Wheel set of the second carriage that ended up alongside the rails. (Source: upper photograph Nedtrain, lower photograph ProRail)

As a consequence of the derailment, a number of passengers suffered minor injuries and the train and rail infrastructure were seriously damaged. Roughly estimated, the value of the damage was approximately 2.5 million euro. The driver of a train travelling in the opposite direction saw the signal jump to red and observed further down to track a fireball and smoke, at which point he halted the train. Because the driver of this train was able to stop in time, a collision with the derailed train was avoided.

2.2 Direct cause

In order to direct trains from one track to another, a switch is equipped with two moving parts, the so-called switch blades (see the parts marked in red in figure 5). Both blades, left and right, are operated by a point machine. The switch in Hilversum was equipped with a point machine of the type EBI switch. The locking rods of the point machine – at least on point machines of the type at switch 3B – are attached at the end (or toe) of the switch blades. The locking rods move the blades into the correct position, so that the passing train will either continue along the straight track or go to the diverging track. When the intercity approached the switch in Hilversum, the blades of the switch were positioned such that the train would continue straight on, as was the intention. However, during the passage of the train, the right-hand switch blade moved, as a consequence of which, unintentionally, the last five carriages were directed to the other track.

Failure of release mechanism

The investigation revealed - as described in detail in appendix C – that the right-hand switch blade was able to change position because the release mechanism in the locking rod of the EBI switch failed.

> 'A run-through event' occurs if a train forcibly pushes the switch blades aside. This generally occurs if the train has passed a signal at red. Generally speaking, a run-through event is accompanied by damage to the switch and/or the train, and can also result in derailment. A release mechanism is primarily intended to prevent damage to the operating system and the switch blades in the case of a run-through event. When activated, the mechanism also prevents the passage of the switch by a subsequent train. A more detailed explanation is provided in appendix B under B.1.2 and B.1.3.

The failure of the release mechanism meant that the two parts of the locking rod were disconnected (see figure 4).

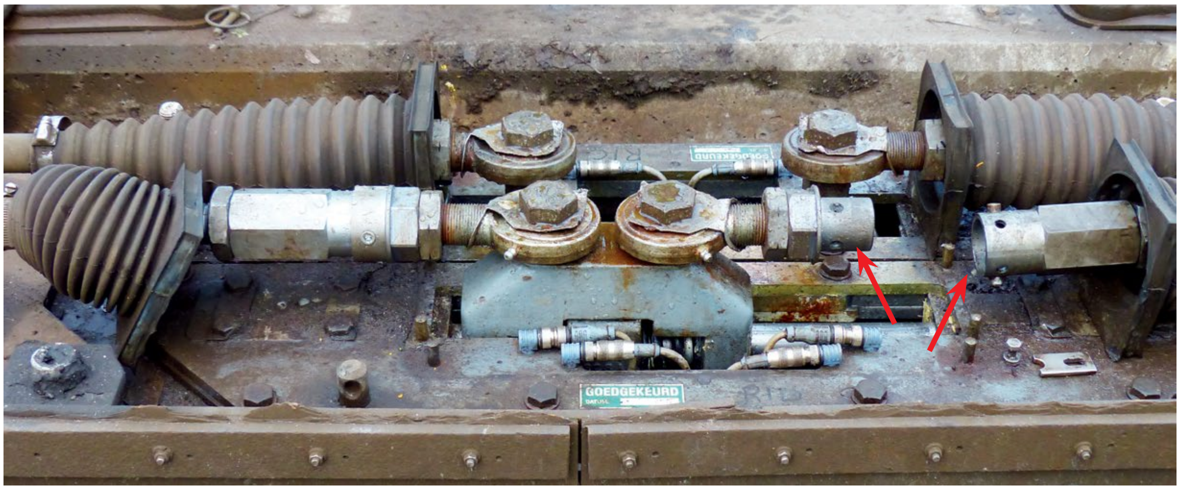

Figure 4: EBI switch in switch 3B: the release mechanism in the right-hand locking rod has failed. (Source: ProRail)

As a consequence, the front section of the right-hand switch blade worked loose and – under the influence of the passing train – this blade shifted from the open position to the locked position (see figure 5). From that moment, both blades were in the locked position. The wheel sets which subsequently reached the switch were as a consequence confronted with a narrowing of the track gauge, in the direction of travel. This is shown in the bottom illustration in figure 5. Both switch blades (shown in red) are in the locked position.

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Because the distance between the switch blades became smaller in the direction of travel, the wheel sets were forced to derail.

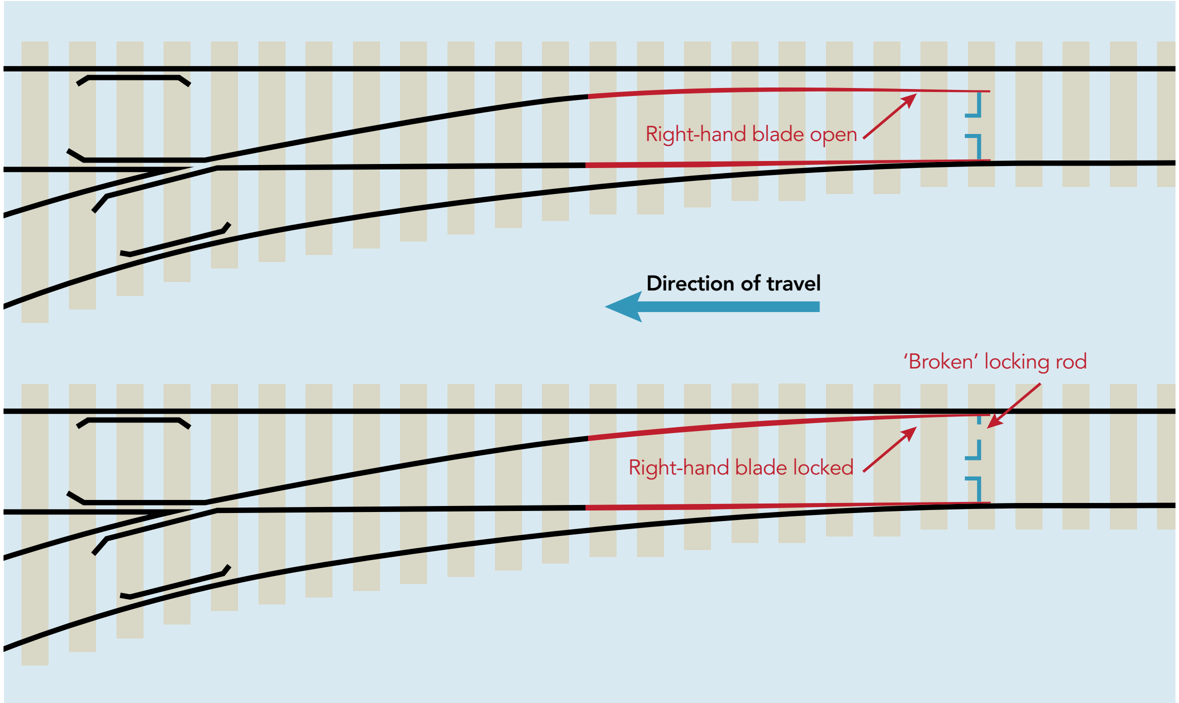

Figure 5: Schematic representation of the cause of the derailment: due to the breaking of the right-hand locking rod, the right-hand switch blade was able to shift from open to locked position.

Ring breaking

The release mechanism of the locking rod failed because the ring, part of the release mechanism, broke in two. The ring is intended to break in a specific situation, namely a run-through event. The photographs below show the ring in question: the left-hand photograph shows an example of an intact ring. The two photographs on the right show the two broken halves of the ring from switch 3B. The ring shows two fracture surfaces. A further explanation is given in appendix C.1.3.

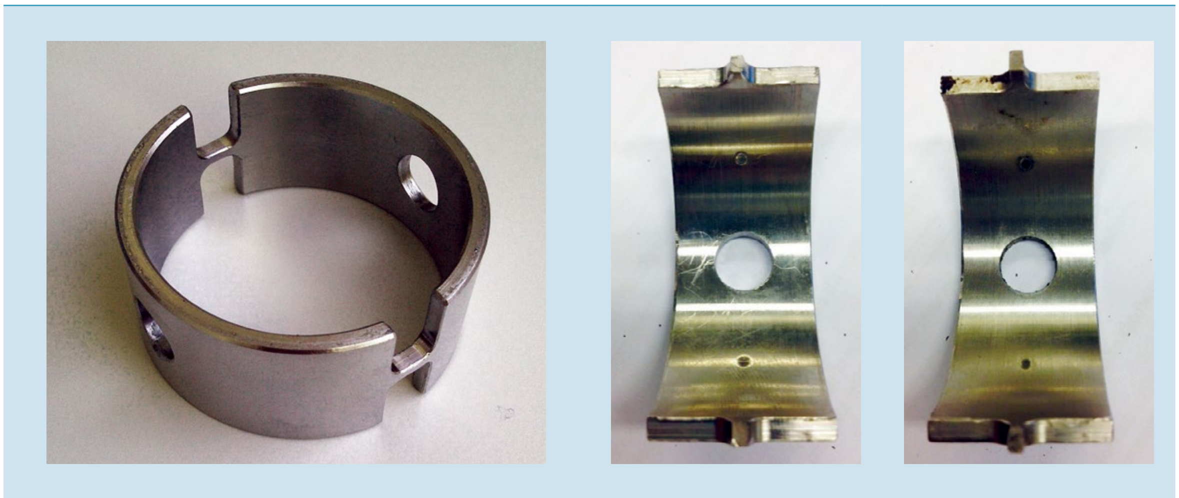

Figure 6: Ring: left an intact example; on the right, the two broken halves of the ring from switch 3B in Hilversum. (Source: ProRail)

The EBI switch

The crossover switches in question in Hilversum were installed forty years ago. Switch 3B was replaced in 2003 and on that occasion, the EBI switch point machine was installed. The same applied for the other three switches in the track section in question in Hilversum. In 1999, the then Dutch infrastructure manager (Railinfrabeheer[3]) opted to purchase point machines of this type. At the time, this was a relatively new type of point machine, with a clearly different concept from the point machine commonly used until that time (like the NSE point machine). The remarkable feature of the EBI switch is that the entire operating mechanism, including the lock, is built into a hollow sleeper. The advantage of this method is that the point machine causes less hindrance during track maintenance.

The EBI switch was designed, manufactured and supplied by Bombardier. As well as in the Netherlands, the EBI switch is used in a number of other countries. In total, Bombardier has sold approximately fifteen hundred EBI switches, of which approximately 70% (more than 1000) to the Dutch infrastructure manager (ProRail) and the remaining 30% to Sweden, Norway and South Korea.

Approximately 15% of all point machines used in the Netherlands are of the type EBI switch. All EBI switches that are in use for the operation of the switch blades[4] are equipped with a release mechanism.

Sub-conclusion

The train derailed at a switch as a consequence of a fracture in a component (ring) in the operating mechanism of that switch.

3 Railinfrabeheer was manager of the rail infrastructure in the period 1995-2005. The company emerged from the Infrabeheer department of Dutch Railways, and was subsequently absorbed into what is today ProRail.

4 A proportion of the EBI switches is used for the operation of movable frogs, and these are not equipped with a release mechanism.

3 ANALYSIS

3 ANALYSIS

3.1 Problem outline

As described in paragraph 2.2, the train derailed because the ring in the release mechanism of the EBI switch in switch 3B broke. A ring of this kind is designed to break at the moment that the switch is run through, but that was not the case in this situation. Technical investigation revealed that the ring broke due to fatigue. The ring in question, that in fact had been installed in the point machine just eighteen months previously, broke well before the end of its standard useful life.

A fatigue fracture occurs when a component is subjected to dynamic forces, which in terms of magnitude and duration (number of changes) are higher than permitted by the fatigue strength. Unlike in the case of an overstress fracture that suddenly occurs, a fatigue fracture arises over a longer period of time. It starts with a small crack which over the course of time and under the influence of a varying load extends further and further. The growth of the fatigue crack continues until the component is so weakened that it fails.

Technical investigation further revealed that the fatigue fracture in the ring was the consequence of the following two causes:[5]

- *The ring found in the switch in Hilversum showed finishing defects*. This ring revealed machining burrs and had a rough grinding spot. These non-conformities meant that the ring was less resistant to load fluctuations.
- *The ring was exposed to additional (and unintended and unforeseen) forces*. The additional load resulted from flange-back contact. Flange-back contact occurs when the insides of the wheel flanges of passing trains scrape against the outside of the switch blade. The process generates an oscillating movement in the blade as a result of which additional forces are applied to the locking rod (which is attached to the toe of the switch blade) of the point machine. The fact that the blade of the switch in Hilversum was hit by the train wheels was due to the technical condition of the switch. Maintenance plays an important role in this respect.

Both issues are further elaborated in paragraphs 3.2 (ring) and 3.3 (maintenance).

In respect of the potential risk, the following can be noted. There are 496 switches of a similar type in the Netherlands, equipped with a point machine of the type EBI switch.

5 See also appendix C under C.1.

In response to the derailment at Hilversum, it emerged that – including switch 3B – 116 of these switches were subject to flange-back contact, and in 16 cases, the ring also revealed machining burrs. It should be noted that at switch 3B, both the flange-back contact and the machining burrs of the ring were relatively serious as compared to the remaining (15) cases in which this combination occurred.

3.2 The ring

3.2.1 Non-conformities in the ring

The ring contains two narrow break links, as shown in figure 7.

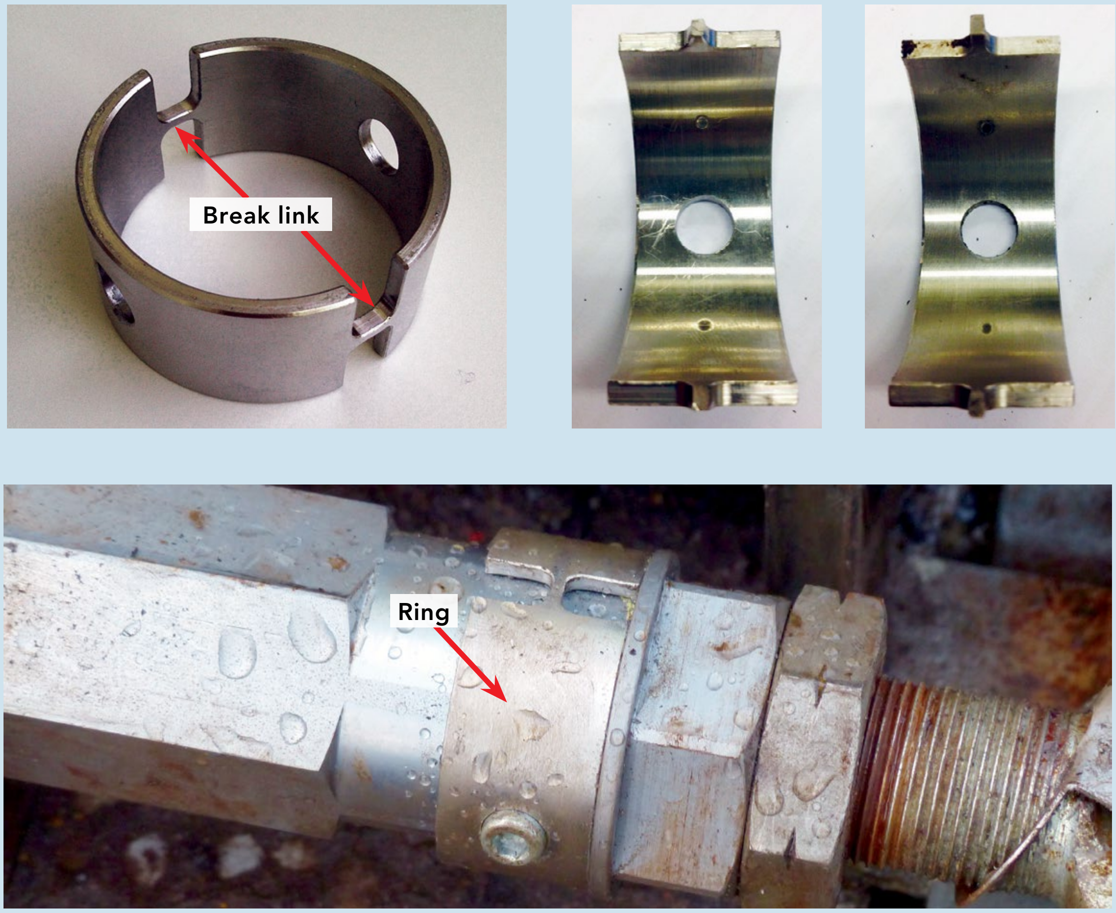

Figure 7: The upper left-hand photograph shows a new ring (with two break links); the upper right-hand photograph shows a broken ring. The lower photograph shows a ring in its installed situation. (Source: ProRail)

The ring found in the switch in Hilversum revealed a rough grinding spot near one break link and burrs near the other. These non-conformities influenced the fatigue strength of the ring. In addition to the dimensions and material characteristics, the fatigue strength is determined by the shape and condition (roughness) of the surface. In final finishing, machining burrs were not correctly removed from this ring: at one break link the burrs remained, while at the other link too much material had been ground away, leading to a rough grinding spot. On the basis of the technical investigation, the Dutch Safety Board considers it probable that first the link with the machining burrs broke as a consequence of fatigue, and subsequently (probably shortly thereafter) the other link broke, causing the ring to fall apart into two pieces.

Sub-conclusion
The ring in the point machine was more susceptible to fatigue due to its poor finish.

3.2.2 Design and manufacture of the ring

Bombardier designed the ring to break at a tensile force of approximately 40 kN. On the one hand, this value is considerably higher (approximately a factor of 10 to 50) than the forces exercised on the ring during the operation of the switch. On the other hand this value is lower than the forces that occur in a run-through event. Assuming that the rings in practice are only exposed to the operating forces (of not more than a few kN), in designing the original ring, Bombardier focused no specific attention on possible fatigue effects.

At the time of purchase of the Dutch EBI switches, which took place around 2001, the railway manager (at that time NS-Railinfrabeheer, today ProRail) didn't address the occurrence of blade hitting (flange-back contact) in our country. Any consequences of flange-back contact, such as fatigue issues, were therefore not discussed.

In the original design of the ring,[6] fatigue was not specifically taken into account. As a consequence, the break link in that ring design had square corners, resulting in a reduction of the fatigue strength. In 2008/2009, Bombardier adjusted the ring design. The reason to adapt the design was the fact that a subcontractor at the time discovered damaged rings in five switches which had not been subject to a run-through event. The break link in these rings turned out to be broken.[7] Further investigation of the damaged rings revealed that in at least one case, there was evidence of a fatigue fracture. Tensile strength tests also showed that of some of the rings, the breaking strength did not meet the requirements. In response, Bombardier adjusted the ring design by applying two break links instead of one and by rounding the corners of the break links[8] (besides some other modifications). Rounding the corners will have positively influenced the fatigue strength of the ring. By applying two break links, the probability that the failure of the ring is detected in time is increased. After the first link has broken, the second link ensures that the ring falls apart into two pieces, as soon as the locking rod in question is exposed to tensile forces. This is the case when the point machine is operated. The failure of the ring will then be detected because the switch 'is brought out of control'. However, even two break links will not guarantee timely detection. It is still possible for

6 The release mechanism, including ring, was designed around 1997, and was initially developed for and in collaboration with a Swedish customer of Bombardier.
7 For more information, see appendix C under C.2.
8 The ring in switch 3B in Hilversum was of the new type. The old ring was replaced in 2012 by a new ring. See also appendix C under C.2.

the second link to break even before the point machine is operated. Such a sequence of events probably occurred in the case of the Hilversum derailment.

During the manufacturing process of the rings, the final finishing and final inspection were not focused on ensuring the optimum fatigue strength During finishing the rings were manually deburred[9] (rather than mechanically) and the quality of the rings was checked randomly. As a result, the non-conformities in the ring, which contributed to the fatigue fracture, could occur. After the ring design was adapted in 2009, the procedures for final finishing and final inspection, as part of the manufacturing process, were not tightened up. Even beyond 2009, deburring was still carried out manually, and quality checks were undertaken on a random sample basis.

Sub-conclusion
In the design of the ring, no account was taken of the possibility of flange-back contacts and the possible consequences thereof for the EBI switch with its release mechanism. During the manufacturing process, the final finishing and final inspection were not focused on ensuring the optimum fatigue strength. The latter not only applies to the original type of ring but also to the type of ring that was (in response to a number of previous incidents) modified in 2009.

3.3 Switch maintenance

Following the derailment, the technical condition of switch 3B was investigated. This investigation revealed that several parts of the switch were seriously worn and that the right-hand switch blade of the switch had been hit. Due to this blade hitting, the ring was exposed to considerably higher and more dynamic forces than those for which it had been designed in the framework of normal use (see appendix C under C.3). The wear on the switch did not just occur overnight. Given the effect on the condition of the switch, maintenance should have led to repair. This did not take place.

3.3.1 Hitting the open switch blade (flange-back contact)

Following the train derailment, a clear wear mark on the locking side of the right-hand switch blade was visible (see figure 8). The mark demonstrates flange-back contact. The depth of the wear mark (up to 1.3 mm) leads to the conclusion that the blade repeatedly must have been hit. The fact that following the accident there was no rust on the wear zone suggests that flange-back contact also recently must have taken place.

9 A burr is a sharp protruding edge which can occur in the machining of metal parts.

Figure 8: Flange-back contact marks on the right-hand switch blade of switch 3B. (Source: ProRail)

The switch parts that have a function in switching the blade and hence in preventing flange-back contacts, demonstrated severe wear. This relates particularly to the slide chairs and the Ekos-V rollers.[10] The Ekos-V rollers, located beneath the mid-section of the switch blade are intended to slightly lift the switch blade so that during movement it experiences less friction. Both Ekos-V rollers in the switch were worn to such an extent that they could no longer fulfil this function. As a consequence, the switch blade scraped over the slide chairs and as a result the slide chairs themselves were severely worn. Due to the resultant friction resistance the right-hand switch blade did not shift far enough when switching from open to locked position.[11] Especially the mid-section of the blade remained too close to the stock rail so that train wheels could scrape along the blade.

Relevant in this connection is the size of 'free wheel clearance'. The free wheel clearance determines the space available for the passing wheels of the train.[12] If this clearance is less than a specified value, the switch blades – at least if the wheel sets of the train comply with the regulations – cannot be hit by the passing wheels. The larger the free wheel clearance, the greater the risk of flange-back contact. Paragraph 4.4.1 discusses the applicable regulations in greater detail. Shortly following the derailment, the free wheel clearance of the switch was measured, and was shown to no longer comply with the standard, operated by ProRail. The possibility that the size of the free wheel clearance changed as a consequence of the derailment can, however, not be excluded.

10 See the explanation in appendix C, under C.1.3
11 The increased friction resistance will also have led to an increase in the operating forces and hence in the load on the switch mechanism.
12 See the explanation in appendix B, under B.2.2.

Sub-conclusion
Parts of the switch in Hilversum were worn. As a result, in its open position, the right-hand switch blade remained too close to the stock rail and was subsequently hit by the wheels of passing trains.

3.3.2 Maintenance on the switch

In railway maintenance, a distinction is made between maintenance on 'the track' and on 'signalling'. Maintenance on the track relates to the correct position and geometry of switches, rails and sleepers, while signal maintenance focuses on the technical installations in and alongside the track, including signals, level crossings and point machines. For maintenance on switches, this means that inspection and maintenance are carried out on both signalling and tracks.

Maintenance on the track
For the purpose of maintenance, the maintenance contractor regularly carries out inspections. These consist of maintenance inspections on the track, video inspections (whereby video recordings of the track are made using a video inspection train) and walking inspections (whereby the track is examined from the inspection path, while walking). Depending on the findings from the inspections, repair work can be necessary, which means that parts have to be adjusted, fixed or replaced. In this report, the term maintenance is used to refer to both inspections and repair work.

Until 1 July 2013, switch 3B was subject to maintenance by Strukton Rail and since 1 July 2013 by Asset Rail. In the framework of this investigation, the maintenance history of switch 3B was analysed.[13] This concerns both maintenance periods.

The most recent track maintenance inspection of switch 3B was carried out in July 2013 by Asset Rail. Subsequently, until the derailment, no further maintenance was carried out on the switch. Asset Rail did inspect the switch (by video and by walking on the inspection patrol path), but these kind of inspections are only suitable for observing 'major' shortcomings. Non-conformities in the Ekos-V rollers and slide chairs are for example not fully observable this way. The next maintenance inspection was planned in December 2013. Because the track section in question could not be released from train traffic (which is an absolute requirement in connection with employee safety), the maintenance

13 Because of the limited distance between the switch and the level crossing, it is to be expected that as a consequence of the deposition of dirt and salt from the crossing, the switch in question will require more maintenance than a switch that is located further away from a level crossing.

inspection was postponed to 20 January 2014. Because of the train derailment several days earlier this inspection never took place.[14]

Viewed over the last few years, in the framework of this investigation, the following special points should be noted:

- *Ekos-V rollers*
  These were last adjusted in 2010. After that time, the switch was inspected but it is unknown whether the setting of the rollers was examined as well. In the measurement sheet for the last track inspection, in July 2013, the Ekos construction was checked being 'ok'.
- *Slide chairs*
  In July 2012, initial signs of wear were observed. In April 2013, the contractor once again observed wear. De degree of wear was not to such an extent that repair or replacement was necessary. It is remarkable that the current maintenance contractor made no report of worn slide chairs in July 2013.
- *Free wheel clearance*
  The free wheel clearance measured by the maintenance contractors complied with the standard operated by ProRail, in all measurements.[15]
- *Flange-back contact*
  In the period 2011 and 2012, during a series of inspections, the maintenance contractor reported flange-back contact. As far as known, neither ProRail nor the contractor took any control measures. In 2013, no further flange-back contact was reported. The fact that flange-back contact still occurred is revealed from recordings by the video inspection train that were made during the last six months prior to the train derailment. The images show alternating evidence of fresh flange-back contact marks (visible as shiny marks). It should be noted that the recordings were in fact only analysed for flange-back contact marks after the train had derailed.

The maintenance history of the switch leads to the conclusion that despite the fact that the free wheel clearance measured by the maintenance contractors complied with the ProRail standard, the right-hand switch blade still was hit. It can also be concluded that the shortcomings in the switch, such as the wear on the Ekos-V rollers, were either not observed, or not dealt with in time.

Maintenance to the point machine
The EBI switch must be serviced once a year. Viewed over the last few years, both maintenance contractors did do so. The EBI switch in switch 3B was last visually inspected on 13 January 2014, just two days before the train derailment. Besides the observation that there was considerable soiling in the point machine, during this inspection no shortcomings in the point machine were observed. According to the contractor, the ring

14 It is not to be expected that the worn Ekos-V rollers and slide chairs would have been replaced during that maintenance inspection. After all, any such replacement requires considerable preparations and especially when the replacement concerns the slide chairs a longer train-free period than normally available for a maintenance inspection.
15 According to measurements carried out on the switch following the derailment, the free wheel clearance didn't comply with the ProRail standard.

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demonstrated no cracks or fractures. Tiny cracks in the ring are indeed difficult to observe with the naked eye.

The maintenance engineer believed that the ring in the switch in Hilversum was of the 'old' type, with one break link instead of two. Because the contractor was conversant with this type, only the break link visible at that moment was inspected. This break link was intact. The other break link was on the underside of the locking rod, and hence beyond the field of vision of the engineer. In practice it is not uncommon that one of the two break links is not immediately visible. In such cases - after temporary removal of a securing pin - the ring can be twisted for a visual inspection of the other break link.

In mid-2012, the ring in the switch in Hilversum was exchanged. The replacement of the old ring by a new type was part of an exchange project concerning all installed EBI switches in the Netherlands. In the communication from ProRail to the contractors, the emphasis was placed more on the locking rods than on the rings. Possibly as a consequence, the modifications to the ring were not fully in the maintenance contractors' minds.

3.3.3 Transition of maintenance contract

Until 2008, ProRail outsourced railway maintenance on the basis of output process contracts (OPC). In that type of contract, the maintenance contractor has a best efforts obligation: ProRail specifies which maintenance work has to be carried out. Since 2008, ProRail switches towards so-called performance-based maintenance (PGO). In PGO contracts, maintenance work is no longer specified, but instead, the requirements with which the railway must comply are laid down. The contractor has a certain degree of freedom in the way those requirements are met.

Because of the transition of the maintenance contract, namely from the OPC contract for Strukton Rail to the PGO contract for Asset Rail, different maintenance regimes were applied. Strukton Rail was subject to the maintenance work specified by ProRail. The administrative records demonstrate that the work was largely carried out according to the intended frequency. Whether that means if the quality of the maintenance was sufficient as well, is hard to say.

Asset Rail executed the maintenance according to its own maintenance regime as approved by ProRail. This maintenance regime is based on an inventory and analysis of the risks (the so-called FMECA: Failure Modes, Effects & Criticality Analysis). Considering the factors that played a role in the occurrence of the train derailment in Hilversum, it can be concluded that the FMECA operated by Asset Rail for switches did not provide for the control of the related risks. The risk of flange-back contacts was absent in the FMECA. The wear on the Ekos-V rollers was acknowledged as a risk, but the executed maintenance regime did not lead to that risk being managed.

Handover
For the transition of the maintenance contract in contract area Eemland, ProRail drew up an 'estate inventory'. The inventory was made by all bidding maintenance contractors being given the opportunity, prior to the tendering procedure, to inspect the area for non-conformities. ProRail merged the inventories undertaken by the contractors into one list of objects to be made non-conformity-free. This list was subsequently supplied to the contractors, to give them an impression of the condition of the railway infrastructure in the area in question. In fact, switch 3B did not occur on that list, which means that none of the contractors notified any non-conformities in switch 3B.

In the framework of the transfer of the maintenance contract from Strukton Rail to Asset Rail, the maintenance history of the area as well was handed over to the new contractor. Because these data were not indexed, the specific issues for switch 3B requiring attention (that weren't dealt with by Strukton Rail because of the termination of the contract) were not explicitly passed on to Asset Rail. Asset Rail itself inspected the switch in July 2013. Noteworthy, the non-conformities previously observed by Strukton Rail were not observed in that particular inspection by Asset Rail.

Sub-conclusion
The maintenance carried out by the subcontractors was not sufficient to maintain the condition of switch 3B at the required level. The wear on the Ekos-V rollers and slide chairs was not dealt with in time. Flange-back contacts were observed, but no control measures were taken. During the most recent inspection of the point machine, only one of the two break links of the ring was inspected.

The above conclusions are reproduced in the following figure.

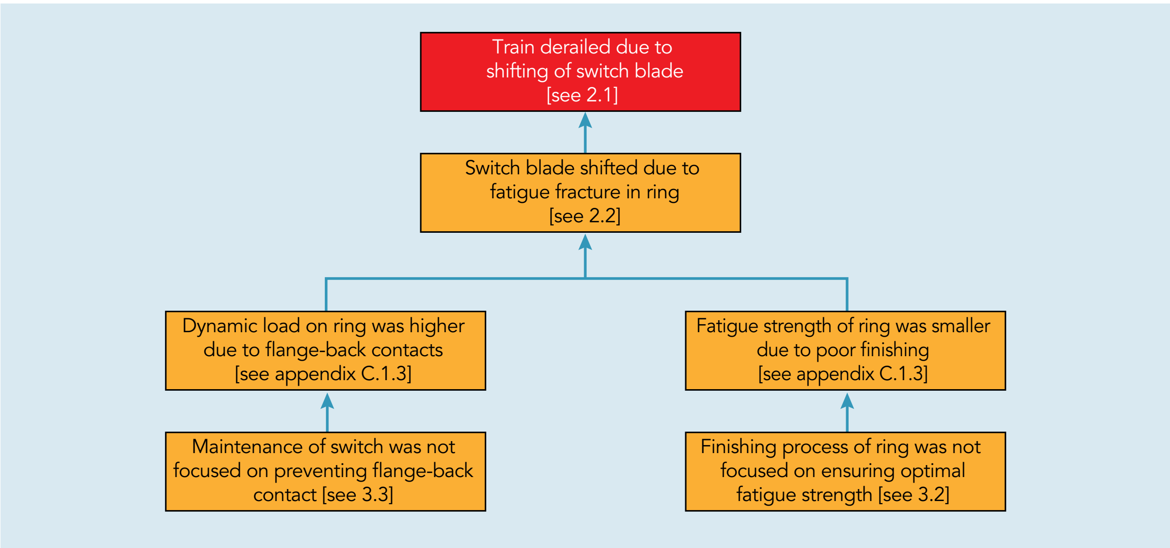

Figure 9: Diagrammatic representation of the direct causes of the derailment.

4 UNDERLYING FACTORS

4 UNDERLYING FACTORS

4.1 Introduction

As described in chapter 3, the train derailment in Hilversum was caused by a failure of the ring in the release mechanism of the switch because this ring i) was more susceptible to fatigue due to finishing defects and ii) was exposed to an additional load due to flange-back contact that repeatedly occurred over a long period of time. The fact that the switch blade was hit was to a large degree caused by the maintenance condition of the switch.

The investigation revealed that both issues were able to occur because the failure mode in question was not acknowledged either by Bombardier or ProRail. They didn't realise that the additional load from flange-back contact could result in a fatigue fracture in the ring. Therefore the finishing process of the rings was not focused on optimum fatigue strength and the maintenance on the switch was not aimed at preventing flange-back contact. In respect of the underlying factors, the primary question which then arises is: why did the parties involved fail to acknowledge the occurring failure mode in good time? It should be noted in this respect that the design of the type of point machine in question dates back to 1996, while the purchase of the machine by ProRail took place around 2002. In this period, flange-back contact was not an unknown phenomenon. At the time, both Bombardier and ProRail were aware of safety management based on inventory and analysis of the risks. Nonetheless, the specific failure mode remained unconsidered until the derailment at Hilversum.

The investigation revealed that in particular the four following issues played a role.

a. ProRail, Bombardier and the maintenance contractors exchanged insufficient information concerning the design and use of the point machine.
b. The focus in maintenance is increasingly aimed at preventing train service disruptions, with the risk that, as a consequence, the attention for safety will be threatened.
c. The degree to which ProRail managed maintenance was limited.
d. ProRail and Bombardier drew insufficient lessons from previous incidents[16] with the EBI switch and from previous comparable train derailments.[17]

These underlying factors are reproduced in figure 10 in diagrammatic form (see the blue blocks) and are further explained in the following paragraphs.

16 See appendix C under C.2.
17 See appendix E.

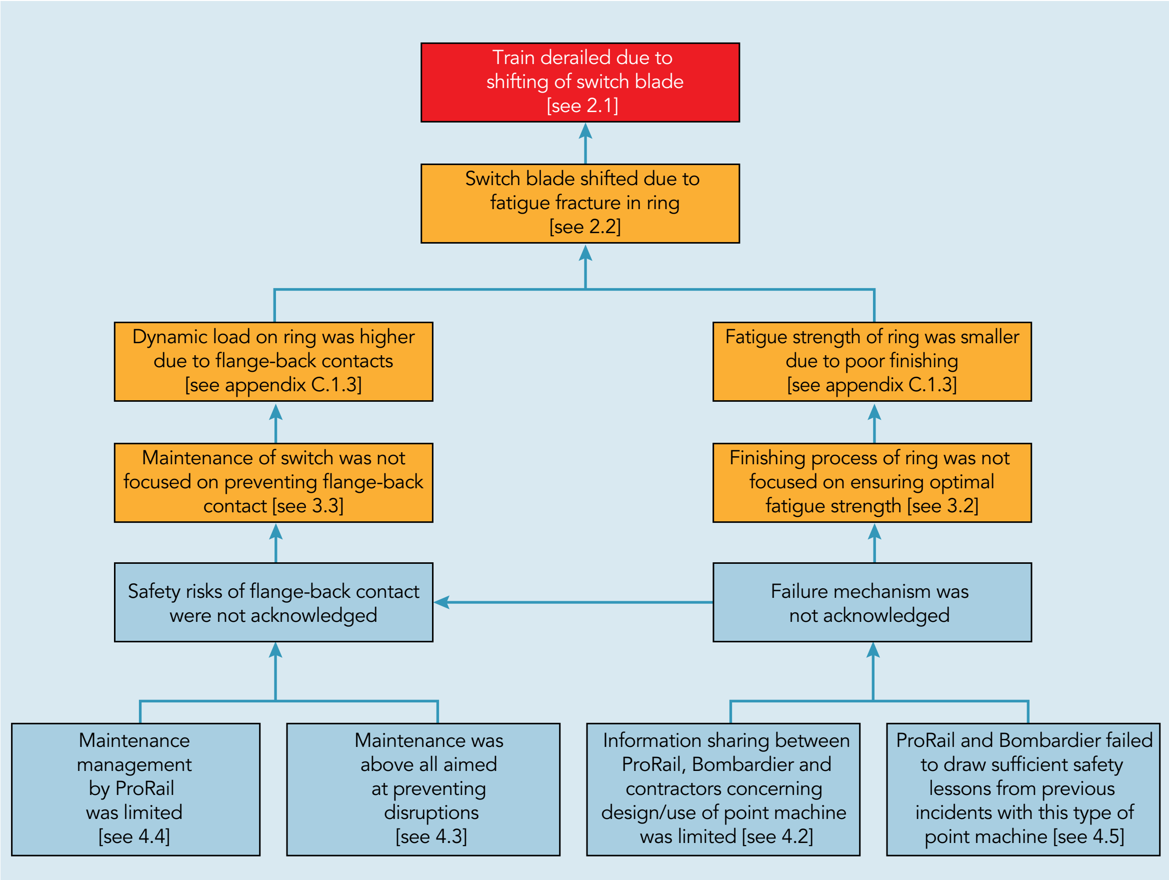

Figure 10: Diagrammatic representation of the failure mode, including underlying factors.

4.2 Knowledge sharing

Harmonisation between design and use of the EBI switch

At the moment that ProRail[18] announced the intention (in 2001/2002) to purchase the EBI switch with release mechanism, ProRail provided the necessary specifications to Bombardier. As already outlined in paragraph 3.2.2, in these specifications, ProRail failed to specify that flange-back contacts can occur in the Netherlands (over long periods of time). ProRail was aware of this fact at the time. That the occurrence of blade hitting was not included in the specifications relates to the fact that ProRail did not view flange-back contact as a safety risk. Also during the user phase, the problem of blade hitting was not specifically referred to in the contacts between the parties (after sales). Previous incidents with the EBI switch in 2008 showed that flange-back contacts did occur and very probably played a role in the occurrence of these incidents.[19] Bombardier was aware of this fact. If this was also the case before that time, is unclear. Bombardier noted that, even after 2008, the company was not aware of the scale on which flange-back contacts did occur on the Dutch railway network.

18 Previously NS-Railinfrabeheer.
19 See also paragraph 4.5 and appendix C, under C.2.

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As supplier of the EBI switch, Bombardier provides customers of the product with an installation and service manual. Bombardier also has drawn up a general safety case relating to the EBI switch, for a general understanding of the point machine. This safety case[20] contains relevant information concerning safety and quality management and technical safety as well. These documents show that in the design of the EBI switch, no account was taken of the possibility of flange-back contacts. In the product specifications for the EBI switch, Bombardier did state that any switch in which the EBI switch is used must be in a good state of maintenance. However, no further consultation took place between ProRail and Bombardier at the time, concerning the practical relevance of this requirement.

The failure to share what has now emerged as being relevant information concerning flange-back contacts made it impossible for either ProRail or Bombardier to acknowledge the safety risk relevant for the accident in Hilversum, in good time. The repeated occurrence of flange-back contacts over a long period of time, in combination with a ring with a limited fatigue strength as a result of finishing defects, led to fatigue.

The flange-back contacts were possible because of the fact that in its maintenance instructions, ProRail deviated from the applicable international standard for the free wheel clearance, as further explained in paragraph 4.4.1. For that reason it was the task of ProRail to check on the extent to which this deviation could lead to safety risks. In that connection, an investigation should have been undertaken to determine whether the EBI switch point machines (including the intrinsic release mechanism) were able to withstand the additional load brought about as a result of flange-back contact.

Exchange of maintenance-specific information
ProRail included the installation and service manual for the EBI switch, supplied by Bombardier, in the maintenance document used by the maintenance contractors for servicing the EBI switch. Two points stand out:

- According to the manual, initial cracks in the ring can be detected by moving a screwdriver back and forth within the break link. It has however been shown in practice that specifically this method can cause damage to the ring, if not carried out with extreme caution. Partly as a consequence, contractors shied away from this method, preferring instead to mainly subject the rings to visual inspection.
- The information about the ring in the maintenance document is out of date: the document describes the old type of ring (with a single break link). With the modification of the ring, Bombardier drew up an updated version of the installation and service manual. This manual describes the new type of ring and explicitly issues the warning that two break links must be inspected. The modifications relating to the design of the ring and its inspection were never placed in the contractors' maintenance document. This partly explains the fact that Asset Rail was not aware that the ring in the switch in Hilversum had two break links.

20 This concerns document 3NSS006386D0067 version 1.6.

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The above points also illustrate that the harmonisation between design and maintenance requires improvement.

Sub-conclusion
Since ProRail and Bombardier (user and supplier respectively) didn't exchange all relevant information about the characteristics and conditions of use of the EBI switch, the safety risk of fatigue in the ring as a consequence of flange-back contacts, was not acknowledged in good time. The initiative for such knowledge sharing could above all be expected from ProRail.

4.3 Focus of maintenance

Initially, railway maintenance was aimed at maintaining the technical condition of the railway infrastructure, with the primary objective to keep it in good condition. It should be noted that in maintaining the sound technical condition, safety risks are also managed. Over the years, a number of changes have taken place, that have influenced the way in which maintenance is executed. The first is that maintenance is increasingly structured from the point of view of making rail transport optimally available. Maintenance work must be accompanied by as few delays as possible. Together with the tightening up of the rules for safe working practice on the railways, this has meant that maintenance can now only be carried out at moments when the track is out of service (no train traffic). This is mainly at night. During night-time hours, a limited number of maintenance hours is available. In addition to pressure of time, despite the use of artificial lighting, working at night reduces visibility for the maintenance engineers. Reduced visibility plays a role in the maintenance of those parts that are dependent on the visual examination by the maintenance engineer. This for example applies to inspecting the ring, observing flange-back contact marks and checking the Ekos-V rollers. In particular the Ekos-V rollers, which are located underneath the switch blade, are difficult to inspect at night.

As concerns railway policy, a transition process is currently going aimed at improving the reliability of the railway (and hence the attractiveness of the railway for passengers) and to introduce cutbacks.[21] This transition affects railway maintenance. Given the social pressure to improve overall railway performance, the prevention of disruptions automatically receives considerable attention. The maintenance of parts that do not directly influence the operation of the switch may as a consequence unintentionally come under pressure. This for example applies to the slide chairs. Non-conformities do not directly result in disruptions, but can have a negative impact on the safe usability over the long term. In addition, performance-based maintenance allows maintenance contractors greater freedom. The transition to performance-based maintenance has been shown in general

21 In this connection, the investigation by the Kuiken Committee "Wissel op de toekomst" plays an important role. In 2012, this committee judged (among other points) that there were concerns about (maintaining) the quality of the railway infrastructure and that in that connection, the Ministry needed to impose strict monitoring and control. As follow-up for the report, the Ministry drew up the Long-Term Railway Agenda (LTSA), in which the policy ambition of Central Government for the longer term was laid down. See also appendix D.

to result in less disruptions and lower maintenance costs. On the one hand this is due to the market forces that are introduced: maintenance contractors compete with one another on the basis price. On the other hand, the contractor is no longer called to account for the effort expended but for the performance delivered. This performance is translated into functional and technical requirements on the railways. The functional requirements relate to the reliability and availability of the railways, and have been made measurable in terms of disruptions and functional repair times. ProRail uses a bonus/malus system to judge the performance of the contractor. With a bonus/malus system, the contractor is called to account on the basis of these requirements. The better the performance (less disruptions, shorter repair times), the more the contractor earns from maintenance. The technical requirements for example relate to safety. Any non-conformities related to the contracted safety requirements must be reported to ProRail by the maintenance contractor. Non-conformities result in a fine. The following issues play a role in that connection. A large proportion of the safety requirements are couched in general terms. The absence of clear, specific standards and rejection values can lead to uncertainties and interpretation differences on whether a relevant non-conformity has or has not occurred. In practice, this can result in a slowly declining railway condition. Furthermore, ProRail itself barely checks whether the infrastructure complies with the safety requirements (see also paragraph 4.4.2). In other words, whether non-conformities in fact emerge, and result in sanctions depends above all on the reports from the contractor. The combination of financial stimuli, open standards and little supervision by ProRail could further exacerbate a situation in which contractors focus above all on preventing disruptions. In itself this is not a problem, as long as this focus is not at the expense of safety-critical maintenance.[22]

In most cases, rail safety will mutually benefit from preventing train disruptions. However, the idea that the railway is safe when there are no disruptions is not automatically valid. This is demonstrated by the derailment in Hilversum. The safety of switch 3B was derived from the free wheel clearance as well as the absence of disruptions. On that basis, it was concluded that the switch was still functioning correctly. This explains the little attention that was paid during maintenance to the Ekos-V rollers and slide chairs. The train derailment demonstrates that the safe usability of a switch also depends on the condition of these parts. It also illustrates the importance of examining the different switch parts more in conjunction with one another. The issue is the safe usability of the switch as a whole. A structure is required to guarantee that such parts, viewed in conjunction with one another and irrespective of the question whether they contribute to disruptions, receive sufficient maintenance.

Sub-conclusion

The importance of improving railway performance is affecting maintenance. Maintenance is carried out almost entirely at night. In addition, maintenance is increasingly focused at preventing disruptions. Therefore, there is a risk that a switch as a whole lacks enough maintenance, which is vital in ensuring the safe usability.

22 The Dutch Safety Board has based its findings on the PGO 2.0 contract applicable for maintenance in the Eemland contract area.

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4.4 Management and supervision of maintenance

4.4.1 ProRail maintenance regulations

ProRail manages maintenance by imposing requirements on maintenance performance. The maintenance contractor must comply with the contracted regulations, while carrying out maintenance. With a view to the fact that the switch was worn, and that flange-back contact occurred, an investigation was undertaken into the extent to which the maintenance regulations imposed by ProRail were of any influence on this. In particular, this relates to the regulations for the Ekos-V rollers, the slide chairs and the free wheel clearance. In the period in which the condition of the switch started to decline, different contracts (OPC and PGO contracts) with different regulations were in place. Wherever those differences are relevant, they are referred to in the text below.

Regulations concerning the Ekos-V rollers and slide chairs

ProRail has drawn up regulations for the maintenance of Ekos-V rollers, which demand that the rollers be adjusted at least every six months. To ensure the correct operation of the Ekos-V rollers, the slide chairs must be replaced (according to the ProRail regulations) if worn by more than 3 mm. This regulation was contained in the Strukton Rail maintenance contract, but in the current maintenance contract with Asset Rail the requirement no longer applies. Besides a general safety net – 'the infrastructure must be in such condition that trains are able to switch without derailing' - no particular safety requirements apply to Ekos-V rollers and slide chairs. In this case, it was up to Asset Rail to guarantee that these parts were well maintained, so that the safe usability was not at risk.

Without regulations and rejection criteria, within maintenance, the professional expertise of the maintenance engineer whose task it is to examine the situation on the ground, is very important. He must know which signals to look out for, and what these signals mean for the functioning of the switch. In the current specialist training for maintenance engineers, provided by training centre 'Rail Infra Opleidingen', the Ekos-V rollers are not part of the examination. ProRail points out which parts are critical and therefore must be examined in the training. These parts do not include the Ekos-V rollers. In other words, a maintenance engineer can successfully pass the exam without any knowledge of the Ekos-V rollers.

Regulations concerning the free wheel clearance

There is a European standard[23] for the free wheel clearance. This standard is so strict (maximum 1380 mm) that under normal circumstances, flange-back contacts will not occur. In its maintenance regulations, ProRail deviates from the European standard, a discrepancy underpinned by a model-based calculation. The calculation showed that the forces from flange-back contacts which are to be expected with such a large clearance (1398 mm), will not bring the point machine out of control.[24] On the basis of this result, ProRail concluded in 2011 that extending the European standard would not result in any problems. No account was taken of any other effects, such as fatigue. ProRail also failed

23 This is a clearance measurement which has been traditionally used in the railway world. However, only since 2011 has the standard been laid down at European level.
24 Error detection when the switch blades are not correctly positioned as intended.

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to carry out any actual measurements. ProRail went on to prepare a further extension of the standard. This standard was ready to be authorised in April 2014. This intention once again illustrates the fact that ProRail never considered flange-back contact as a safety risk. As a consequence of the train derailment in Hilversum, ProRail decided to not implement the further extension of the standard.

In respect of the free wheel clearance, the most critical situation arises when following the switch of the blade from locked to open position, no trains have yet passed. The position of the open switch blade, if it remains too close to the stock rail, has at that point not yet been corrected by passing trains. It is essential that the free wheel clearance is measured in this most critical situation. Switch 3B was only switched on a few occasions each day. The likelihood that this took place just before an inspection moment is particularly small. It is very probable that the most critical situation never occurred at those moments when the switch was inspected. At those moments, the right-hand switch blade was far enough away from the stock rail (after all, the passing trains had shifted the switch blade sideways, thereby correcting the free wheel clearance), as a result of which the measured values complied with the standard. To simulate the most critical situation, the maintenance engineer himself needs to switch the blades, before measuring the free wheel clearance. This requirement is not laid down in the maintenance regulations from ProRail, but is an essential one. As a consequence, the maintenance engineers did not carry out their measurements in this way. This is the probable explanation for the fact that no non-conformities in the free wheel clearance were measured at switch 3B, while during the same period, flange-back contacts repeatedly occurred.

Furthermore, the maintenance documentation does not require that switch blades should be regularly inspected for evidence of flange-back contact.

Sub-conclusion
The maintenance regulations from ProRail are insufficient to prevent flange-back contacts. For the free wheel clearance, a standard is employed which, in the view of the Safety Board not sufficiently underpinned, deviates from the European standard, and as a consequence permits flange-back contacts to occur. The instructions for measuring the free wheel clearance are incomplete. Furthermore, there is no requirement that the switch blades should be regularly inspected for evidence of flange back contact. Depending on the type of contract, requirements are or are not imposed on the maintenance of Ekos-V rollers and slide chairs.

4.4.2 Supervision by ProRail
ProRail entrusts the execution of maintenance to contractors. In its role as contract-awarding party, ProRail should monitor the contractor's work and the results of it. ProRail meets this obligation by carrying out administrative checks and outside inspections on the railway infrastructure. The outside inspections are carried out randomly and, in connection with the safety rules, are generally carried out from inspection patrol paths.

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Reporting non-conformities
It is laid down contractually that the maintenance contractor must report any non-conformities to ProRail. The reporting obligation relates only to non-conformities from standards contained in the contract. Over the past year, the maintenance contractors reported no problems with switch 3B relating to the Ekos-V rollers, the slide chairs or the free wheel clearance. The free wheel clearance complied. There were no standards for the Ekos-V rollers and slide chairs. From a contractual point of view, in other words, regarding these components, there was nothing that had to be reported as a 'non-conformity'.

Aside from the reporting obligation referred to above, each month, the maintenance contractor is required to report on the most important geometric values of the switch, including the free wheel clearance, to ProRail. Studies of a number of monthly reports from the maintenance contract area in question reveal that the majority of the reported non-conformities in switches related to the free wheel clearance. Several cases where the free wheel clearance exceeded the standard were accepted by ProRail with the decision to refrain from any repair. This was based on the idea that exceeding the standard would not result in any safety risk.[25] Because the free wheel clearance measured at switch 3B complied with the standard, no special results emerged from the report concerning this switch.

ProRail inspections
Besides carrying out a check of the administration of the completed work orders and the submitted reports, ProRail did not check whether the maintenance on switch 3B had in fact been correctly carried out, and whether the regulations were complied with. Certainly over the past few years, ProRail has not inspected switch 3B, not even from the inspection patrol path. This explains why switch 3B remained in use while it was in poor condition. In this respect, switch 3B was not an exception. The other three switches on the relevant section of track in Hilversum, namely switches 1A, 1B and 3A showed similar wear as well. ProRail was also not aware of this situation.

In every PGO contract area, ProRail bases the inspections to be carried out on an inventory of the risks in that area. The nature of the risks will depend on the area-specific characteristics. For the contract area to which Hilversum belongs, neither the risk inventory nor the assessment plan had yet been drawn up. In other words, ProRail had no idea of the railway elements in the Eemland area which required additional maintenance attention.

Sub-conclusion
ProRail had no idea of the maintenance condition of switch 3B. ProRail failed to check whether the maintenance on switch 3B complied with the regulations and whether the switch was safe.

25 This observation matches the findings of the ILT in the investigation into the decommissioning of switches and tracks in The Hague and Rotterdam on 19 February 2014 and the investigation into the effects of performance-based maintenance on the safe use of the Dutch railway infrastructure as presented to the Dutch Lower Chamber on 21 February 2014.

4.5 Learning from incidents and accidents

Previous problems with the EBI switch

In 2008, problems arose with some EBI switches in use in the Netherlands.[26] In two cases, these problems related to excessive wear on a threaded connection of the locking rod. In five other cases, the ring was cracked. At the time, both Bombardier and ProRail carried out an investigation into these incidents. In respect of the problems with the threaded connection of the locking rods, the conclusion was that the problems were in all probability caused by a combination of corrosion and (exceptional) vibrations. In respect of the rings, it was concluded that in at least one case, the fracture was the result of fatigue while in a number of the other rings, it was possible that an installation error had played a role. It furthermore became clear that the breaking strength of a number of the rings was not within the proposed limits.[27] Based on these investigations, at the time, Bombardier adjusted the design of the ring and the threaded connection. As the locking rod concerns, the decision was taken that the two parts which were originally joined together by a threaded connection would in the future be manufactured in a single section. As the ring concerns, the construction was adapted so that installation errors were no longer possible, and the number of break links was raised from one to two.
At the same time, the square corners of the break links were rounded, so that they would be less susceptible to fatigue.

The investigations revealed that flange-back contacts had probably also played a role in the problems in 2008. Further investigation into that phenomenon was carried out at the time, in the form of measurements on switches in which the open blade was hit. These measurements revealed that flange-back contact is accompanied by a severe oscillating (swinging) motion in the switch blade itself. It also became clear that this oscillating movement of the switch blade imposed an additional mechanical load on the point machine. However, at the time, no further investigation was carried out into the degree of this additional load on the switch mechanism or into the scale at which this phenomenon occurred on the Dutch railway network. There was also no investigation into the extent to which that extra load could possibly result in fatigue, for example in the ring or other components in the point machine. At the time, neither Bombardier nor ProRail acknowledged the risk that flange-back contacts could lead to a fatigue fracture in the ring. In that connection, Bombardier commented that at the time it did state in its report that further investigation into the potential risks of flange-back contacts was necessary. As far as is currently known, such additional investigation was not initiated by ProRail (neither by Bombardier).

Way in which parties learn

In hindsight, it can be argued that in previous incidents with the EBI switch Bombardier and ProRail focused (too much) on solving the immediate problem. This is a way of learning also demonstrated by parties following the train derailment in Hilversum: the train derailment results in one or more investigations and on that basis, specific measures are taken in order to solve the immediate problems. These measures for example include

26 See appendix C, under C.2.
27 For more information, see appendix C under C.2.

alterations to the design (installing a technical safety net and adjusting the ring) and any accompanying (maintenance) instructions for the product, or increasing the stroke of the point machine.[28] In the judgement of the Dutch Safety Board, however, it may be expected that the underlying issues were also dealt with. These underlying issues for example concern alterations to the internal organisation, the mutual cooperation and/or the exchange of information. Bombardier did to some extent demonstrate this way of learning in 2008/2009, in the sense that the design of the ring was modified in order to be able to more accurately dimension the breaking strength. The results of the investigations undertaken at that time, however, should then also have led to a (joint) rethink on the design and manufacture of the ring on the one hand as well as on the maintenance of switches on the other hand. Because of the distribution of tasks and the fact that the problems related to an abnormal load during use, it was above all up to ProRail to take the initiative.

Comparable train accidents
The parties in question could have acknowledged the risks of flange-back contacts at an earlier stage, on the basis of two train accidents abroad. In 2002 and 2007, two very serious derailments with passenger trains occurred in England, in Potters Bar and Grayrigg respectively (see also appendix F). In both derailments, the immediate cause lay in faulty, broken switch components, and the phenomenon of flange-back contact (most probably) played an important role in their occurrence. The accidents demonstrate that blade hitting, and the resultant occurrence of fractures are not unique to the situation in Hilversum. Although public investigation reports have been published about these accidents, both parties were not aware of their content, and no specific safety lessons were drawn from the reports.

In addition to the train accidents in Potters Bar and Grayrigg, other train accidents have occurred in the past in the Netherlands and abroad, which in some respect show similarities to the derailment in Hilversum. The derailment of a goods train in Dordrecht in 2006, for example, was the consequence of poor switch maintenance. Furthermore, at the time, the Transport, Public Works and Water Management Inspectorate (Inspectie Verkeer en Waterstaat - IVW) concluded that ProRail had insufficient insight into the technical condition of the railway infrastructure. Eight years on, insufficient switch maintenance turns out to have also played a role in the train derailment in Hilversum. A train accident in Hatfield (England) in 2000 also showed evidence of poor railway infrastructure maintenance. The investigation into this accident moreover revealed that the railway infrastructure manager had insufficient insight into the technical condition of the railway network.

Exchange at European level
Railway parties can be expected to learn from incidents and train accidents both at home and abroad. From around 2007, the European Railway Agency (ERA) provides an overview of the incidents and recommendations published by national investigation bodies. This so-called ERAIL database makes information relevant to railway safety in the Member States of the European Union available and transparent for all interested parties and

28 See appendix F for the actions in response to the derailment in Hilversum.

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stakeholders on the railways. Safety lessons can be shared with one another. Member States are required to issue investigation reports to the ERA. The ERAIL database currently allows all parties to draw lessons for their own practice, wherever necessary. At the time of the purchase of the EBI switch and the derailments in England, this database was not available, and in 2008 the database had not long been operational. It is expected that knowledge interchange about international accidents will take place more smoothly nowadays. The platform has a valuable function, and could be of importance for the various parties involved in the development, production, installation, management and maintenance of (parts of) the railway infrastructure, and as a consequence of importance for railway safety.

Sub-conclusion

In previous problems with the EBI switch, ProRail and Bombardier restricted themselves to eradicating the immediate causes. Also following the derailment in Hilversum, this same response seems to have taken place. In their analyses, parties have not sufficiently investigated the heart of the problem and the underlying causes. It also emerges that no lessons have been learned from comparable train derailments abroad. Because of the distribution of tasks and the nature of the problem, ProRail was the most obvious party to take the initiative and control in this connection.

5 CONCLUSIONS

5 CONCLUSIONS

5.1 Introduction

The Dutch Safety Board carried out an investigation into the derailment of a passenger train that took place on 15 January 2014 at Hilversum. At the time of the derailment, the train was travelling in a straight direction over a switch. When derailing the rear section of the train was directed to the adjacent track. A train travelling in the opposite direction on the adjacent track was successfully brought to a standstill approximately two hundred metres before reaching the derailment site, as a result of which a collision was avoided. As a consequence of the derailment a number of passengers suffered minor injuries and serious material damage was caused to the track infrastructure and the train.

The investigation focused on answering the following two investigation questions:

1. *What was the direct cause of the train derailment?*
2. *Why did the parties whose task it was to guarantee that the switch could be passed safely fail to prevent the derailment?*

5.2 Direct cause

The train derailed at a switch as a consequence of a fatigue fracture in the operating mechanism of that switch.

The train derailed as a result of the fact that during the passage of a switch, the switch mechanism failed as a consequence of a fatigue fracture. The fatigue fracture arose because the part in question (ring) was in practice exposed to a higher mechanical load than had been taken into account in the design. This was because the manufacturer of the point machine (Bombardier) and the railway infrastructure manager (ProRail) operated different principles in respect of the load on the point machine. The manufacturer assumed that the ring would only be exposed to normal operating forces. The railway infrastructure manager permitted flange-back contact to occur, as a consequence of which additional, dynamic forces were also applied. Furthermore, the ring itself demonstrated finishing defects, making it more susceptible to fatigue.

5.3 Safety shortcomings

The companies directly involved failed to acknowledge the risk of flange-back contacts.

The phenomenon of flange-back contact is not restricted to switch 3B in Hilversum, but in fact occurs in a large proportion of the switches installed in the Dutch railway network. When a switch blade is hit, clearly visible flange marks are left on the locked side of the switch blade. ProRail, the responsible maintenance contractors (Strukton Rail and Asset Rail) and Bombardier were all aware of the occurrence of this phenomenon. Bombardier was not informed of the extent to which flange-back contacts occurred. ProRail and the contractors (either consciously or unconsciously) assumed that there were no safety risks involved. However, as the derailment in Hilversum and previous train derailments in Potters Bar (England, 2002) and Grayrigg (England, 2007) have shown, such risks are clearly present. The impact of hitting the blade causes an oscillating motion in the switch blade, which in turn leads to an additional mechanical load as well as to additional vibrations. In turn, these can cause fatigue, accelerated wear (in particular on the parts that support the movement of the blade) and loose threaded connections.

The companies involved failed to share all relevant information about design, use and maintenance with one another, as a consequence of which the failure mode was not identified in time. The initiative for such knowledge sharing must above all be expected from ProRail.

The safe usability of a switch is the result of the cooperation between the relevant parties. Together it is their task to ensure that design, use and maintenance are harmonised in such a way that no safety shortcomings arise. ProRail, the maintenance contractors and Bombardier, however, failed to exchange all the information essential to perform this task. Bombardier, for example, was not aware of the scale at which the phenomenon of flange-back contact occurred on the Dutch railway network. On the other hand, neither ProRail nor the maintenance contractors realised that (the extra load caused by) flange-back contact was beyond the scope of the user specifications of the point machines supplied by Bombardier. This lack of knowledge sharing meant that maintenance on the switch was not focused on preventing flange-back contact. Because the consequence of allowing flange-back contact to take place was that the point machine was exposed to an abnormal load, ProRail (as infrastructure manager) was the most obvious party to take the lead in this knowledge sharing process.

In earlier technical problems with the EBI switch, ProRail and Bombardier focused above all on eradicating the immediate causes: no broader perspective on learning was demonstrated.

Technical problems have occurred previously (2008) on a number of EBI switch point machines (in use in the Netherlands). At the time, Bombardier and ProRail investigated the problems, and on that basis modifications were implemented to solve the problems in question. It became clear from the investigation that in these problems, too, flange-back contact probably played a role. Further investigation revealed that flange-back contacts generated additional forces to which the point machine was exposed. However, neither Bombardier nor ProRail investigated the extent to which this extra load could lead to the fatigue of components in the point machine, like the ring.

The safety risks of flange-back contact could have been acknowledged in time if the safety lessons from two derailments which occurred previously in England had been picked up on.

Two very serious derailments involving passenger trains occurred in England, in 2002 and 2007, whereby (most likely) the phenomenon of flange-back contact played an important role. It emerged from the investigations carried out at that time, of which public reports have been published, that the mechanical load on a switch can rise considerably as a consequence of flange-back contact. The outcome is that the technical service life of a switch can be massively reduced. Unlike the situation in England, these safety lessons were not picked up on in the maintenance of the Dutch railway infrastructure. It should be noted that the European Railway Agency (ERA) that today fulfils an essential role in the international exchange of safety investigations into railway accidents was not yet (effectively) operational at that time.

ProRail operates maintenance regulations that are insufficient to prevent flange-back contact.

The blade of the switch in question in Hilversum was repeatedly hit. These flange-back contacts were the result of the maintenance condition of the switch. Various parts of the switch were so worn that they were no longer able to fulfil their function, namely soundly supporting the movement of the switch blade. The investigation revealed that the maintenance regulations from ProRail are not sufficient to prevent flange-back contact. The most important standard (for the 'free wheel clearance') is too wide, deviates from the European standard and is not strictly complied with. Furthermore, there are gaps in the regulations imposed on the contractor. These shortcomings are insufficiently

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compensated for by suitable maintenance. This situation was exacerbated by the fact that six months prior to the train derailment, a change in maintenance contractor had taken place, whereby the maintenance condition of the switch in question was not explicitly discussed.

> Maintenance is increasingly focused on preventing disruptions to train services. This engenders the risk that a switch will not be examined as a whole, while such complete examination is vital in ensuring the safe usability.

The derailment in Hilversum demonstrated that a switch can exhibit safety-technical defects, without these being observed. These defects were not reflected by disruptions, as a consequence of which the switch did not receive the attention it needed. According to its performance-based maintenance, ProRail no longer specifies which maintenance work has to be carried out, but focuses instead on the performance to be provided. Related to this, the concrete maintenance regulations and technical specifications are restricted, and it is more up to the contractor to decide on the maintenance work to be executed. The maintenance is in part controlled with a system of financial stimuli. The freedom granted to contractors and the incentives mentioned can bring about a situation whereby attention within maintenance (short-term) is focused heavily on reducing disruptions. A focus of this kind can threaten safety-critical maintenance on a switch (long-term) if such maintenance is not directly necessary in order to keep the switch disruption-free. A situation whereby a number of switch parts receive insufficient maintenance also arose in Hilversum. On the one hand, this fact illustrates the importance of examining the various switch parts together rather than individually. After all, the objective is the safe condition of the switch as a whole. The safe condition depends on a number of mutually-influencing factors. On the other hand, it is essential that the management and control of maintenance leave no space for unmanaged safety risks. There must be a guarantee that the maintenance contractors will actually execute all maintenance necessary for safety. ProRail supervised the execution of maintenance mainly on paper, and had no idea of the actual condition of the switch. As a consequence, a heavily-used switch had become unsafe, without this situation being observed.

> Developments in railway infrastructure management may place the safety of rail transport under pressure.

A number of developments are taking place in railway infrastructure management, the aim of which is to improve the reliability of rail transport (and hence its attractiveness for passengers) while at the same time reducing the management costs. This trend is reflected in the way maintenance is managed and executed. With a view to the events in Hilversum, and also seen in the light of the results of the investigation reports published in 2014 by the ILT on railway infrastructure maintenance, the Safety Board views a source of concern.

Originally, railway infrastructure maintenance was aimed at maintaining the sound technical condition of the railway, to keep the infrastructure in good condition. Today, railway infrastructure maintenance is above all focused on a trouble-free operation of the train timetable. There is nothing wrong with this objective, as long as it is not strived for at the expense of safety. Furthermore, maintenance work can only be carried out when there is no train traffic, in order to comply with the labour safety requirements. In other words, transport and maintenance can no longer be carried out simultaneously. As a consequence, maintenance needs to be carried out in less time and is restricted mostly to the night hours. In order to make maintenance more efficient and cheaper, market forces have been introduced in railway infrastructure maintenance. Contractors compete with one another on the basis of price. Maintenance has acquired a commercial character, resulting in the unavoidable accompanying interplay of forces.

Seen against the background of these developments, and the related commercial interests in maintenance, boundaries are gradually shifting. As a consequence, unintentionally and unnoticed, parties are running the risk of compromising too much on railway safety. The train derailment in Hilversum is an example of the possible consequences of such a situation.

6 RECOMMENDATIONS

On the basis of its investigations, the Dutch Safety Board has issued the following recommendations:

To ProRail

1. Organise railway maintenance in such a way that the safety risks are explicitly and demonstrably managed, irrespective of other interests (such as availability and costs). Develop stimuli for maintenance contracts that offer contractors maximum encouragement in actively promoting railway safety. Monitor to ensure that contractors actually carry out the necessary maintenance and that this maintenance has the desired result.
2. Ensure that relevant design, user and maintenance information on all railway infrastructure parts is available to the various chain partners. Also encourage active knowledge sharing on (near) accidents and innovative developments (both nationally and internationally).
3. Tighten up regulations governing the (design, laying and inspection/maintenance of) switches in such a way that flange-back contacts are effectively countered. Incorporate the tightened regulations as mandatory in the (current and future) contractual agreements with the companies involved.

To ProRail and the maintenance contractors

4. Together, ensure an up-to-date and complete picture of the technical condition of the railway infrastructure. Use this information for adequate management (asset management) whereby – besides monitoring the functionality and service life – safety is demonstrably guaranteed.
5. Make sure when transferring a maintenance contract, that all relevant information about the technical condition and maintenance history of the railway infrastructure in question is transferred fully and in an accessible manner to the future contractor.

To Bombardier

6. When supplying railway parts (such as the EBI switch point machine), provide users with clear, safety-related user specifications. Monitor to ensure that these requirements are met in practice, and warn users if this is not the case.

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To the State Secretary for Infrastructure and the Environment

7. Make sure that the safe usability of the railway infrastructure is granted sufficient weight in relation to other interests (such as capacity and punctuality). Integrate this vision in the current rethink of the policy framework for railway safety, and bring about a situation whereby ProRail and the maintenance contractors are able to successfully act in accordance with it.

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JUSTIFICATION OF INVESTIGATION

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APPENDIX A

JUSTIFICATION OF INVESTIGATION

A.1 Investigation approach

The investigation into the train derailment in Hilversum was dealt with via a two-phase approach, whereby phase one was broadly an initial investigation while phase two examined the situation in greater depth. In phase one, information was gathered about the facts and circumstances that led to the derailment. On the basis of information obtained, the facts of the accident and the technical causes were charted out. The second phase of the investigation focused on the organisation of the underlying processes that explain the occurrence of the incident.

In respect of the investigation, as much information as possible was gathered about the train derailment and the underlying problems. This information was obtained by visiting the derailment site shortly following the accident, consulting documents and by questioning the parties both in writing and verbally, in the form of interviews. The results of technical investigations undertaken by ProRail and Plurel were also included in the overall investigation. In the judgement of the Dutch Safety Board, the technical soundness of these investigations is of such a level that the Board made use of the results, without undertaking any independent technical investigations.

NS investigated the wheel sets of the derailed train. This investigation revealed that the train in question was not a contributing factor to the occurrence of the accident. There was no further cause to assume that the derailment related to the rolling stock in the broader sense. For this reason, the rolling stock was not considered as a causal factor, and the investigation was restricted to the infrastructure.

A.2 Review

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

- ProRail;
- Bombardier Transportation Netherlands BV;
- Asset Rail;
- Strukton Rail;
- Human Environment and Transport Inspectorate (Inspectie Leefomgeving en Transport);
- Ministry of Infrastructure and the Environment (Ministerie van Infrastructuur en Milieu);
- NS Reizigers.

The parties responded to the draft version of the report. The comments received were processed as follows:

Corrections to factual errors, additions at detail level and editorial comments were adopted by the Board (where relevant). The appropriate text sections in the final report were revised. These comments have not been separately listed.

Wherever the Dutch Safety Board did not adopt the comments, an explanation is provided of why the Board so decided. These comments and the explanatory notes are contained in a table available on the website of the Dutch Safety Board: (www.onderzoeksraad.nl, www.safetyboard.nl).

A.3 Guidance committee

For this investigation, the Dutch Safety Board appointed a guidance committee. This committee was made up of external members with expertise relevant to the investigation, chaired by a member of the Dutch Safety Board. The external members were represented on the guidance committee in a private capacity. The guidance committee met on three occasions during the investigation, to exchange ideas with the Board and the project team on the structure and results of the investigation. The committee fulfilled an advisory role within the investigation. Final responsibility for the report and the recommendations lies with the Dutch Safety Board.

E.R. Muller (chair)	Vice-chairman Dutch Safety Board
G.P.M.R. Dewulf	Professor of Planning and development, Faculty of Engineering Technology, University of Twente
J.C.H.G. Arts	Chair Executive Board Flevoziekenhuis, Former member of the Executive Board of ProRail (2004-2008)
A.W. Veenman	Former President-director NV Nederlandse Spoorwegen (2002-2009)
C. Esveld	Director Esveld Consulting Services, Former professor of Rail Engineering, TU Delft (1993-2006)
W.W. Veeneman	Senior lecturer and section leader Policy Organization, Law and Gaming, Faculty of Technology, Policy and Management, TU Delft

A.4 Project team

The investigation was undertaken by the following project team, under the responsibility of investigation manager A. Bovens:

A. van der Zande	project manager
A. Sloetjes	investigator
T. van Prooijen	investigator
S. Pijnse van der Aa	investigator
E. de Croon	analyticus

In the investigation, use was made of the expertise of R. Liemburg, A.A. Wedzinga and W.J. Zwanenburg.

APPENDIX B

TECHNICAL TERMS

APPENDIX B

TECHNICAL TERMS

B.1 Switch

B1.1 Construction and operation of a switch

A switch is a track construction that allows a train to be directed from one track to another. A switch consists of static and moving parts, indicated in black and red respectively, in the figure below.

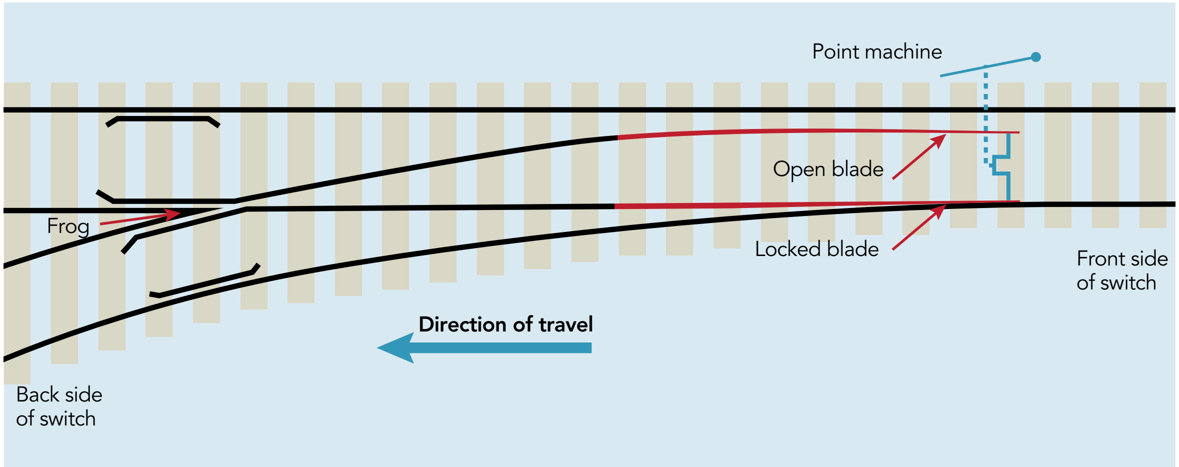

Figure 11: The main parts of a switch

The movable parts that direct the train from one track to another are known as switch blades. A switch has two switch blades (a left-hand and a right-hand blade) which both shift to the left or right, as the switch is operated. The shifting (switching) of the switch blades is achieved by the point machine. The point machine consists of a drive motor that is linked to the toes of both switch blades, by rods. In long switches, either more point machines are used, or the point machine is at more points connected to the switch blades. The point machine also has a locking device (with which the position of the switch blades can be fixed) and a detection mechanism (which detects whether the blades are in the intended position).

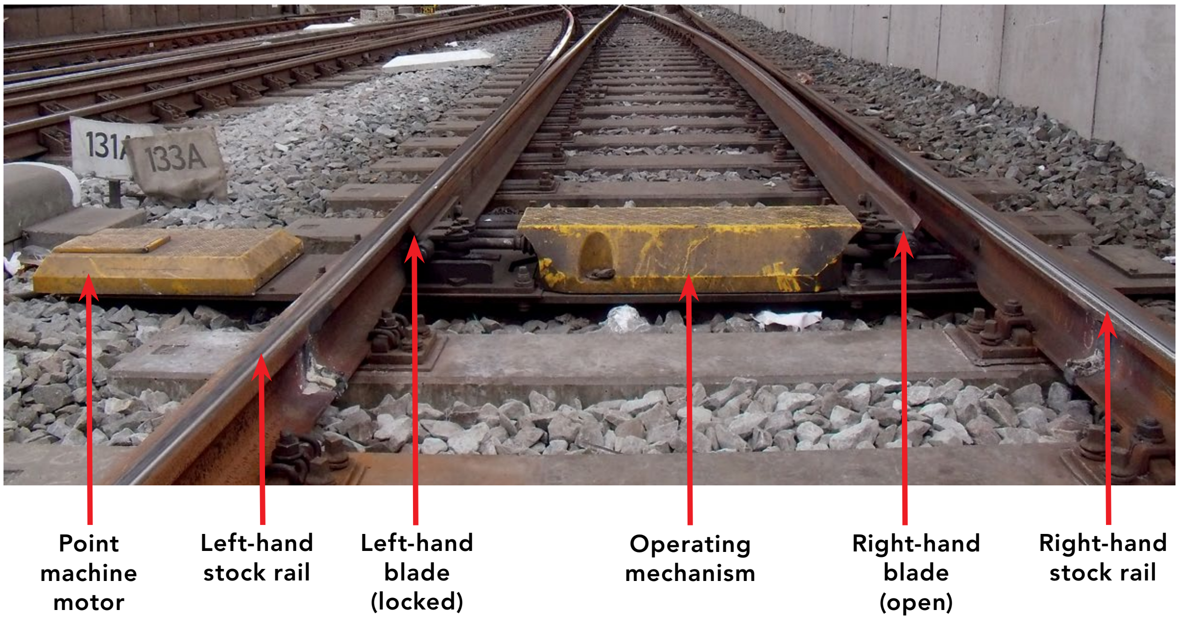

Figure 12: This photograph shows a point machine of the type EBI switch. (Source: ProRail)

The switch blades rest on steel plates (the so-called slide chairs) that are themselves mounted on top of the sleepers. To reduce resistance during shifting (switching) of the blades, a so-called Ekos-V system can be fitted below the mid-section of the blade. That system consists of horizontal rollers that are mounted on a spring construction and protrude slightly above the slide chairs. The Ekos-V-system lifts the switch blade slightly, so that during switching, the underside of the switch blade does not drag over the slide chairs. When train wheels travel over the switch blade, the rollers are forced downwards, and the underside of the switch blade rests temporarily on the slide chairs.

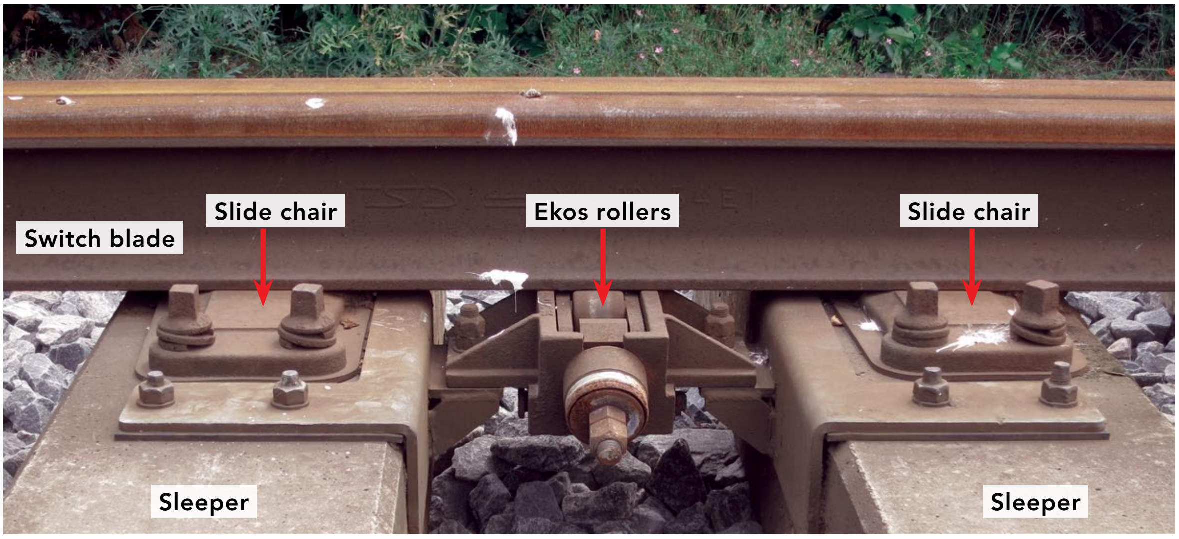

Figure 13: This photograph shows the parts supporting the switch blade, consisting of slide chairs and Ekos-V rollers.

The point machine can shift the end of the switch blades (the blade toes) backwards and forwards. In the two maximum positions, the front section of one blade is in contact with the static rail (stock rail) while the front section of the other blade is some distance away from the stock rail. These blade positions are described as locked and open, respectively.

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Only these two maximum positions, where both blade toes are found in their most left-hand or most right-hand possible position, allow the safe passage of a train. Depending on whether the position of the blade does or does not change the direction of the passing train, the switch position is described as 'to diverging track' or 'to straight track' (see figure 14).

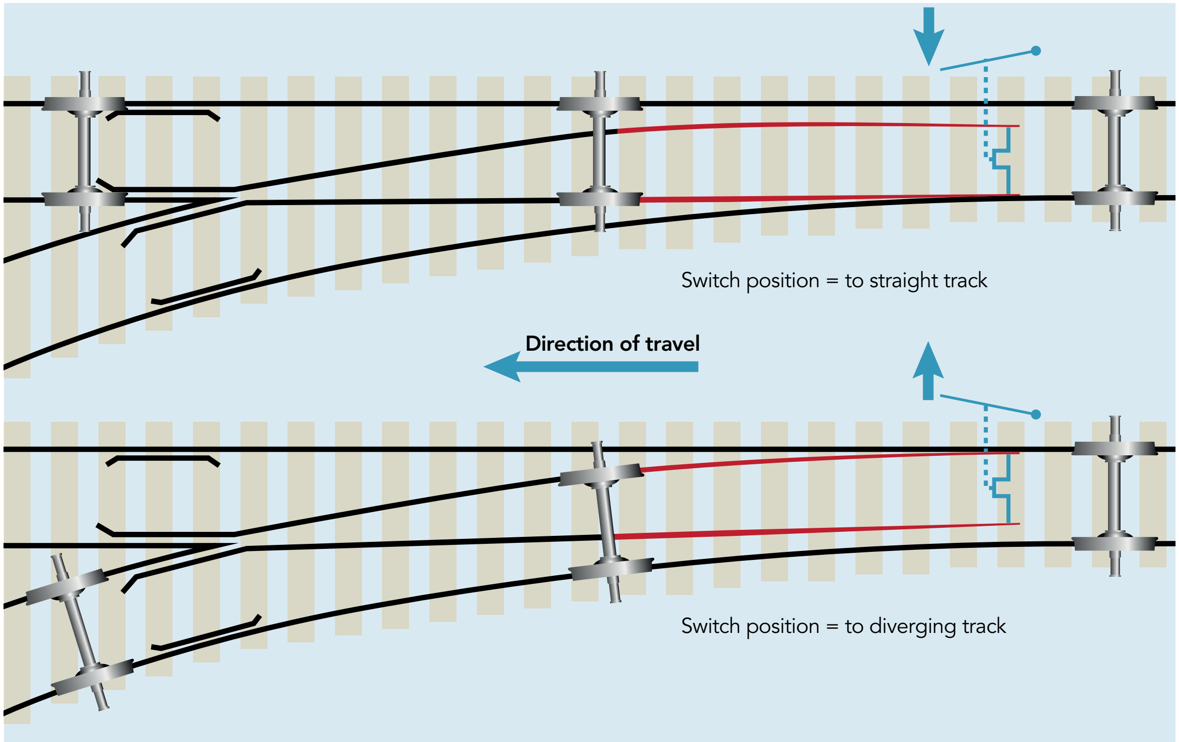

Figure 14: The operating principle of a switch.

B1.2 Running through the switch (a run-through event)

The 'running through of a switch' means that a train (or separate railway vehicle) passes a switch from the back, where the switch blades are in the wrong position (to straight track or to diverging track). A manoeuvre of this kind, which is generally accompanied by damage to the switch and/or the train, can normally speaking only occur if the train follows a route which has not been released, and is generally preceded by passing a signal at red.

In a run-through event, the switch blades are pushed aside (run through) by the wheels of the train. If the position of the switch blades is fixed (which is normally speaking the case), the blades are pushed aside with massive forces that are applied to the switch blades themselves and to the point machine. These forces can cause serious damage to those parts. Besides that they could lead to the derailment of the train. If a run-through event remains unnoticed, there is a risk that the next train to pass the switch will derail as a result of the damage caused.

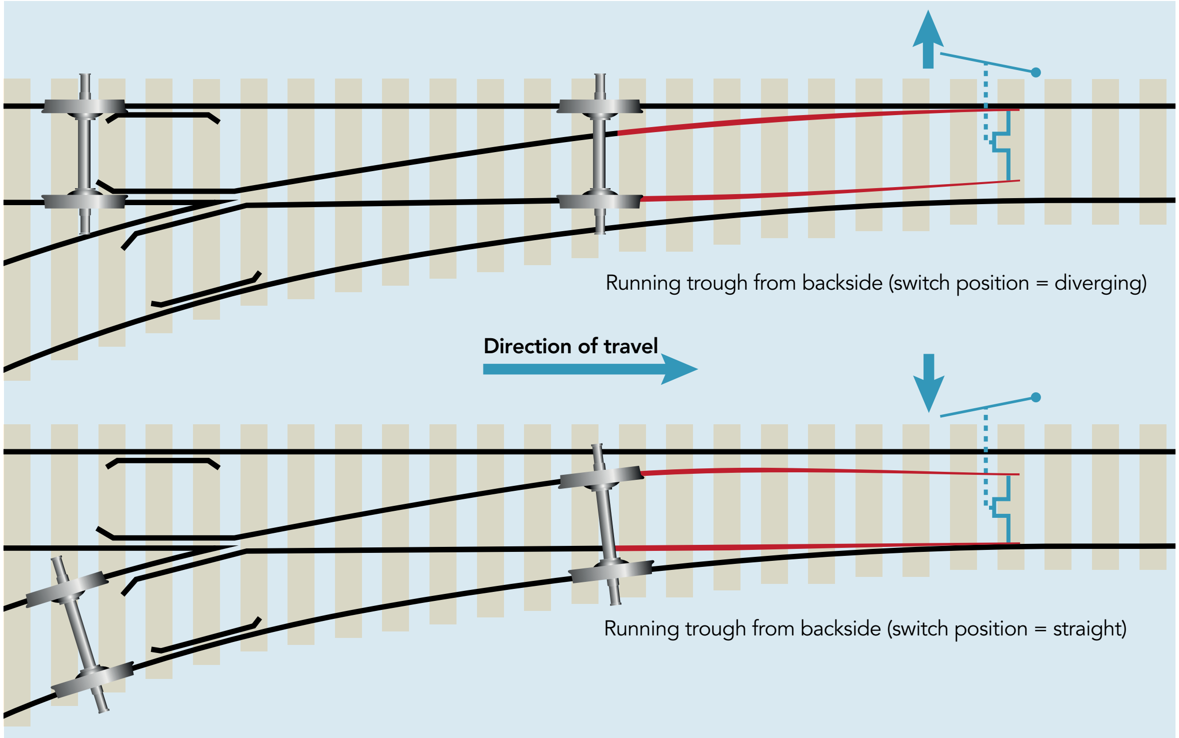

Figure 15: The running through of a switch.

B1.3 Release mechanism

A release mechanism is a mechanism fitted in a point machine, the purpose of which is to break the connection between the switch blades and the locking device in the case of a run-through event. By breaking that connection, the switch blade can move freely, as a result of which it can be pushed aside without excessive forces being applied. As a result, it is more likely that the switch blade will be pushed so far to the side that it is detected by the detection mechanism, and a signal is passed on to the safety system (as a consequence of which the switch in question cannot be automatically released for the next train). Additional advantages of breaking the connection between switch blade and locking device are that when the switch is run through less damage will be caused to the switch blades and the switch mechanism, and that the risk of derailment is reduced.

The photograph in figure 16 shows a point machine of the type EBI switch with release mechanism (in a workshop configuration). The motor and the locking device are contained in a hollow steel sleeper (in this case black) with the system of rods forming the link to the switch blades mounted on top.

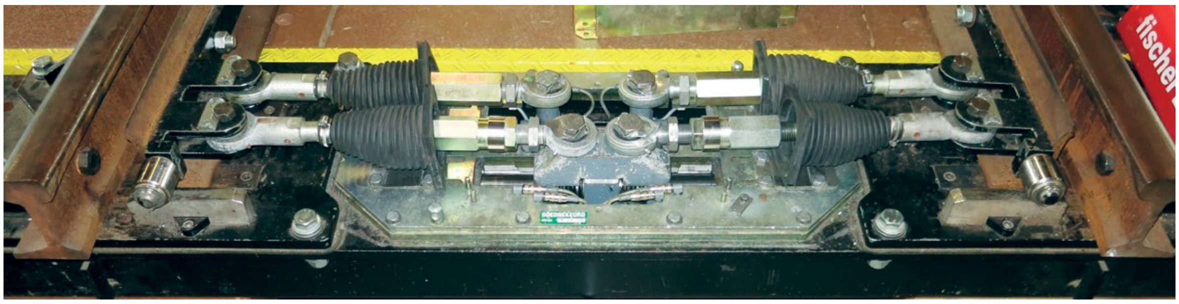

Figure 16: An EBI switch point machine (workshop configuration).

The photograph in figure 17 shows the system of rods of an EBI switch with release mechanism. In this case it is the point machine for switch 3B in Hilversum. The two front rods are the locking rods (that link the switch blades to the drive motor and the locking device) while the rear rods are the detection rods (used to detect the position of the switch blades). The two front rods are equipped with a release mechanism: the left-hand rod is intact, the right-hand rod is 'broken'.

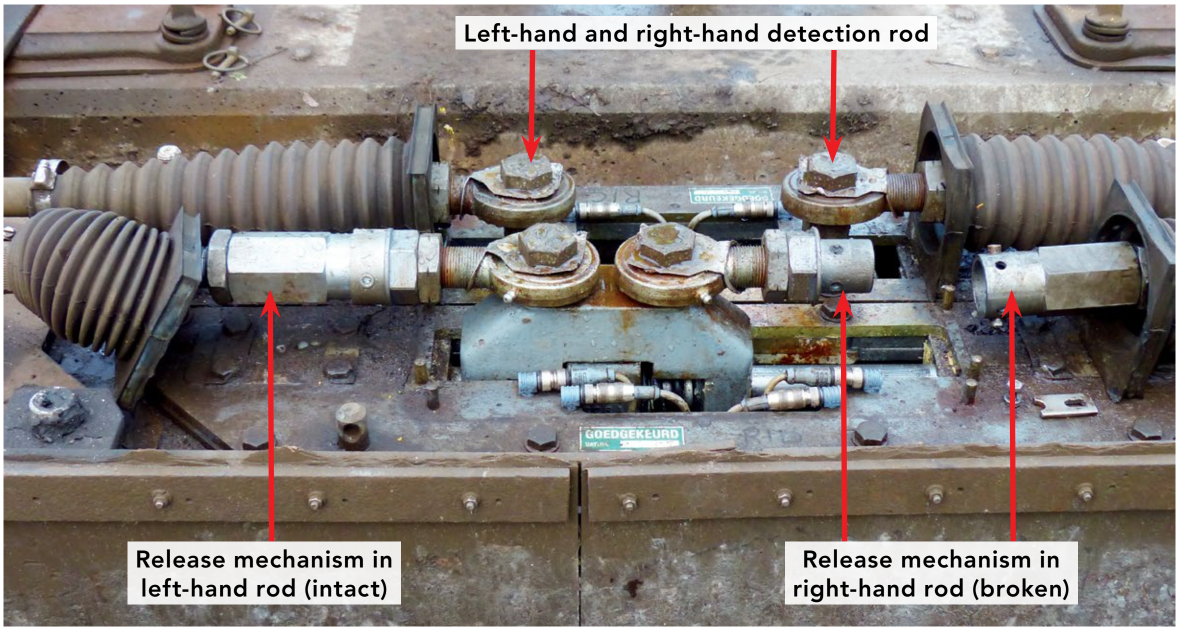

Figure 17: The locking and detection rods in switch 3B. (Source: ProRail)

B.2 Hitting the switch blade and free wheel clearance (fwc)

B2.1 Hitting the switch blade (flange-back contact)

When an open switch blade is positioned too close to the stock rail, it is possible that the inside of the passing train wheels will come into contact with the outside of the switch blade. This situation (see figure 18) is referred to as 'hitting the open blade'.

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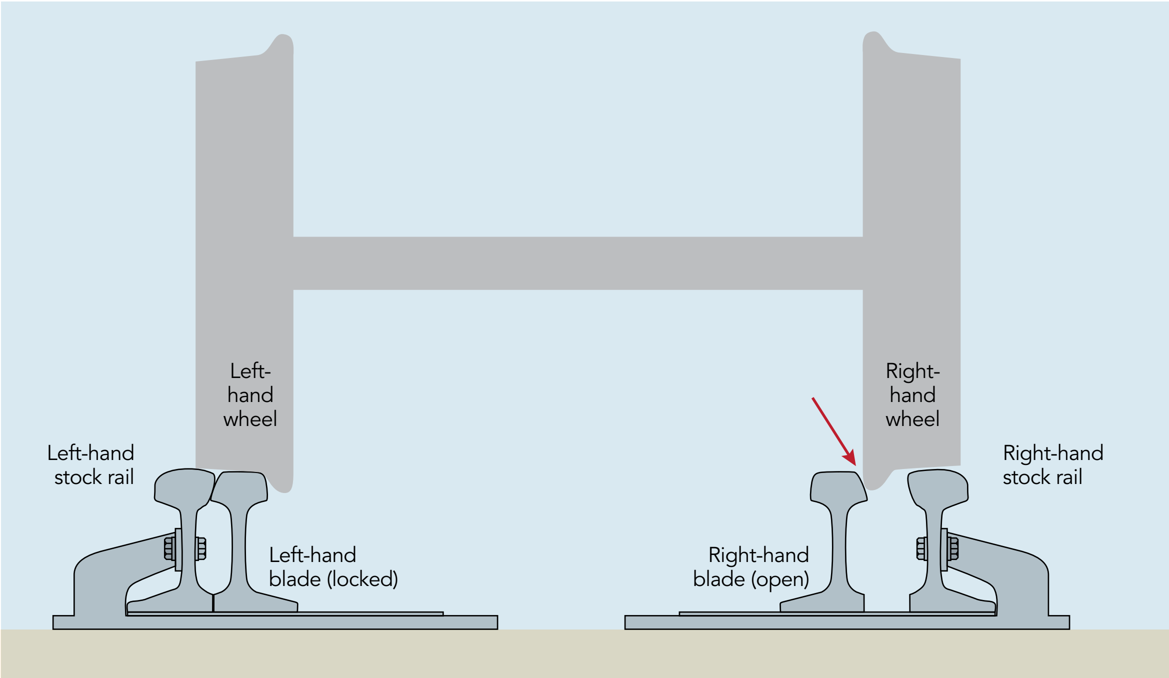

Figure 18: Hitting the open switch blade.

Hitting an open blade generally occurs around the mid-section of the blade, if that section shifts not far enough when the blade is switched to the open position (meaning that it remains positioned too close to the stock rail). To counter this situation, broadly speaking the following three measures are possible: ensuring minimum friction when moving the blade (for example by lubricating the slide chairs or by using a so-called 'lubrication-free system'), increasing the stroke of the point machine and fitting a panel below the foot of the blade at the heel attachment. As previously mentioned, it is also possible to connect the switch blade to the switch mechanism not only at the toe but at several other points. This is known as multipoint operation.

When a switch blade is hit, it takes on an oscillating (wobbling) motion, which in turn leads to dynamic tensile and compression forces on the parts to which the blade at both ends is attached. On the one hand, this refers to the connecting or curved rail (to which the heel of the blade is attached) and on the other hand to the locking rod (which is attached to the toe of the switch blade) and the parts of the point machine connected to it. The oscillating motion of the switch blade will also cause additional wear on the parts that support the switch blade (the slide chairs and any lubrication-free system). Furthermore, the flange-back contact causes the switch and the point machine to be exposed to additional vibrations. These additional forces and vibrations can negatively influence the technical condition and useful life, for example in the sense that they cause screw connections to work loose and/or lead to the occurrence of fatigue fractures.

B2.2 Free wheel clearance and flange-back clearance

Hitting an open blade can occur if the 'free wheel clearance' is too large or 'the flange-back clearance' is too small (see the next figure). The free wheel clearance is the distance between the inside of the locked blade and the outside of the open blade; the flange-back clearance is the distance between the open blade and the stock rail.

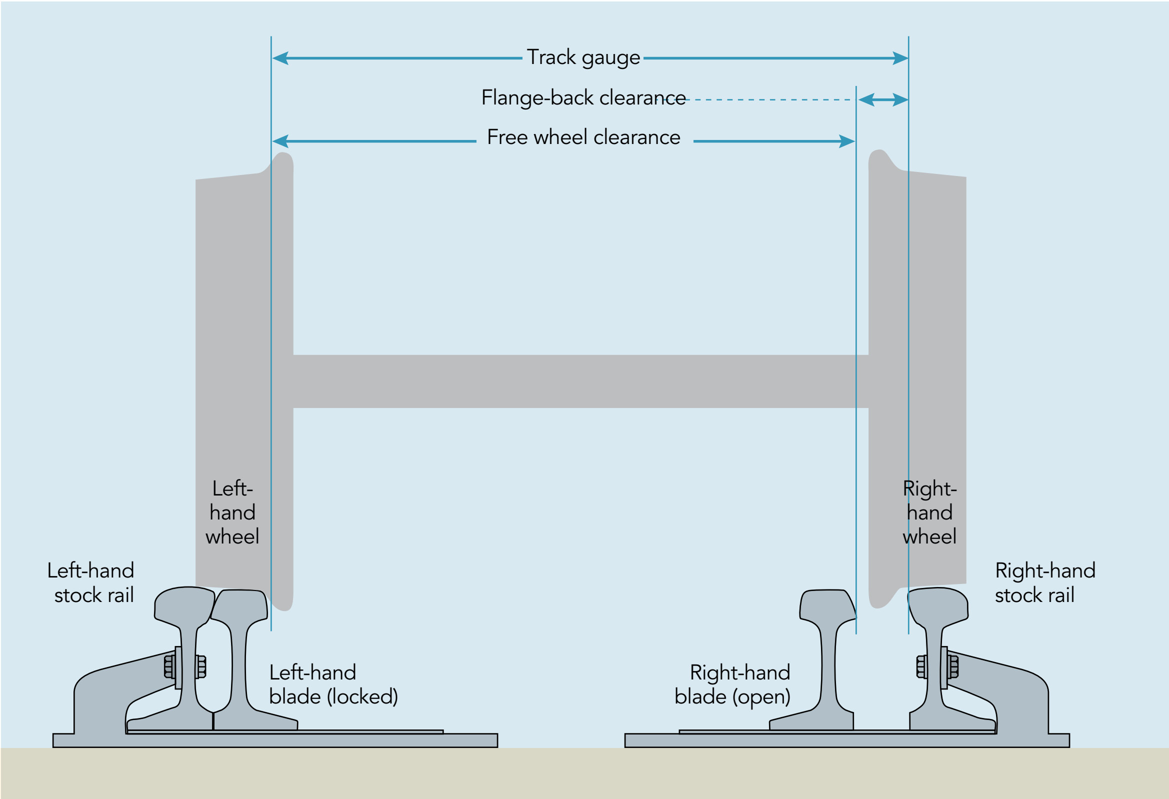

Figure 19: The relationship between track gauge, free wheel clearance and flange-back clearance.

According to the European Directives (TSI-INF),[29] the free wheel clearance must be less than 1380 mm. Only when it is demonstrated that the point machine can withstand flange-back contact may this standard be deviated from. This standard is matched to the regulations for the geometry of wheel sets. The TSI-RS demands that on wheel sets, the inside gauge is more than at least 1357 mm and the flange thickness more than 23 mm, making the sum of these two distances at least 1380 mm (see figure 20). In the current regulations from ProRail, for the free wheel clearance, the following values are employed: target value ≤ 1380 mm, treshold value ≤ 1390 mm and safety value ≤ 1398 mm.[30]

29 In formal terms, the TSI-INF only applies to the track infrastructure that is/was put in use following the introduction of the TSI on 1 June 2011.
30 In paragraph 4.3.3, the difference between the European Directive and the ProRail regulations is described in further detail.

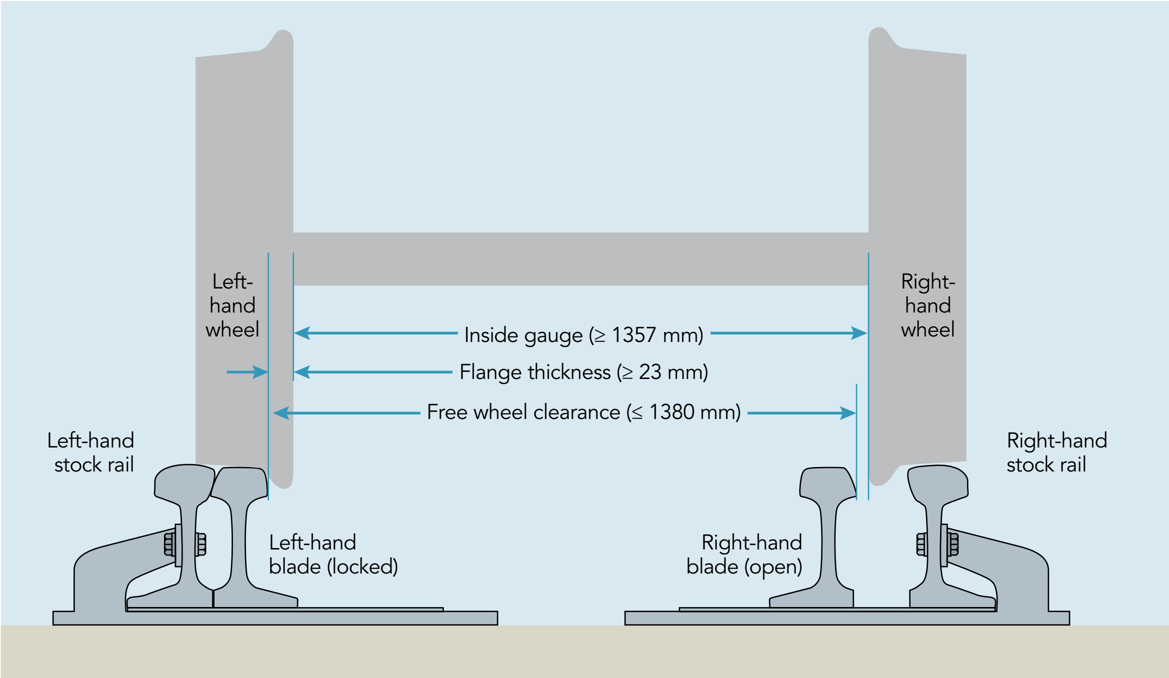

Figure 20: The relationship between inside gauge and flange thickness of a wheel set on the one hand and the free wheel clearance of a switch on the other hand.

B.3 Fatigue fracture

A fatigue fracture occurs when a part is exposed to dynamic forces, which in terms of magnitude and duration (number of changes) are higher than permitted by the fatigue strength of that part. The fatigue strength of a part, in addition to its dimensions and material characteristics, is determined by the shape and condition (roughness) of the surface. Unlike in the case of a an overstress fracture that suddenly occurs, a fatigue fracture occurs over a long period of time. A fatigue fracture starts with a small crack which over the course of time and under the influence of a dynamic load extends further and further. The growth of the crack continues until the part is so weakened that it fails.

In a fatigue fracture, the fracture surface generally reveals two sections: one section is the result of the extension of the fatigue crack itself, while the other section is the consequence of the residual fracture. The fatigue-related section of the fracture surface generally shows shell markings, which are sometimes only visible under a microscope. A second characteristic is that in the fatigue-related section of the fracture surface, there is generally no evidence of deformation (necking) at the edges.

APPENDIX C

TECHNICAL FINDINGS OF THE INVESTIGATION

TECHNICAL FINDINGS OF THE INVESTIGATION

This appendix provides a summary of the technical findings of the investigation. The first section (C.1) relates to the accident and causes of the derailment in Hilversum. The second section (C.2) relates to a number of previous incidents (2008) with point machines of the same type as involved in the derailment in Hilversum.

C.1 Derailment in Hilversum

C.1.1 Train and location

The derailed train bore train number 1652 and consisted of two train sets of the type ICM (with three and four carriages respectively).[31] The train was carrying approximately 550 passengers.

Figure 21: This photograph shows a train of the same type as that involved in the derailment, consisting of two train sets with three and four carriages, respectively of the type ICM. (Source: Hermine Broggel)

The ground plan in figure 22 shows the situation at the scene. The track section in question comprises two tracks, containing two sets of crossover switches ((3-A/B and 1-A/B). As seen from the direction of travel, the switches are located closely beyond a level crossing.[32]

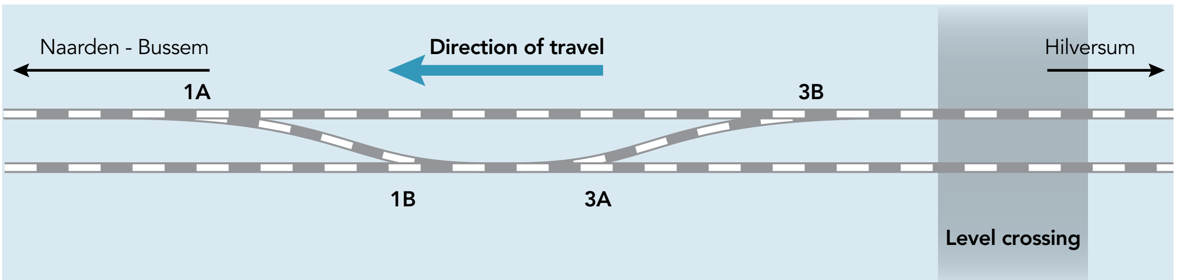

Figure 22: The situation at the accident location (schematic representation).

31 The front train set (4053) consisted of carriages NLNS94844387053-0, NLNS94844389053-8 and NLNS94844388053-9, and the rear train set (4202) of the carriages NLNS94844390202-8, NLNS94844393202-5, NLNS94844391202-6 and NLNS94844391202-7.

32 The level crossing in question is level crossing 28.0, located on the Hoge Larenseweg in Hilversum.

The next photograph shows the accident location viewed from the direction of travel of the train. In the foreground the level crossing is visible, with the two crossover switches beyond.

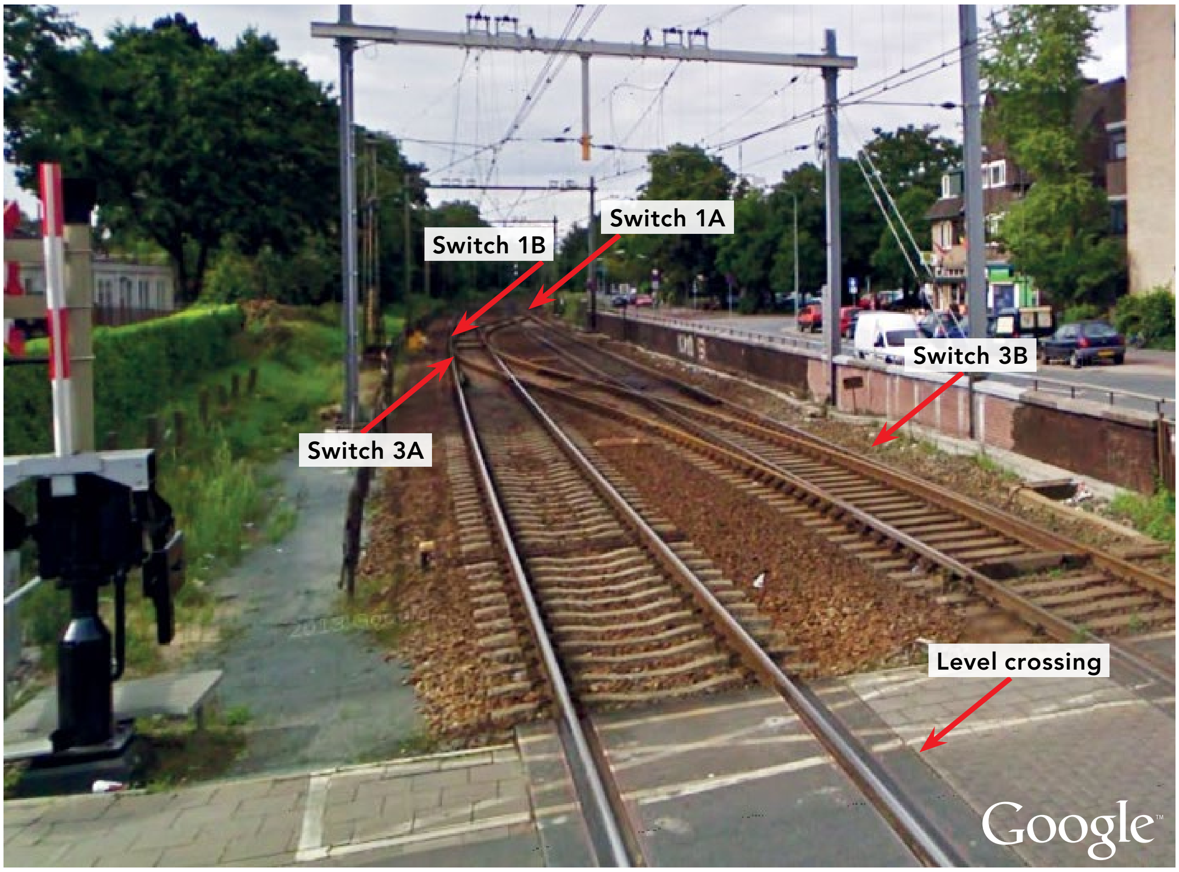

Figure 23: The photograph shows the accident location viewed from the direction of travel of the train. In the foreground the level crossing is visible with just beyond it the two crossover switches between the left-hand and the right-hand track. (Source: Google earth)

C.1.2 Course of movement, final situation and consequences

The course of movement of the train during and following the derailment was recorded by four video cameras installed in the area surrounding the level crossing. These recordings reveal, in combination with the damage left behind on the sleepers by the wheel sets, that the train followed the route as presented in figure 24:

- In the upper drawing, the train approaches switch 3B.
- In the second drawing the train is in the position that the derailment starts: after the front three bogies have travelled straight on at switch 3B, the fourth bogie (below the rear section of the second carriage) derails.
- The third drawing shows that the derailed fourth bogey subsequently moves to the left and ends up on the left-hand track. The same then happens with the subsequent bogies.
- The fourth drawing shows that during the run-out movement (which lasts approximately two hundred metres), the bogies that are directed to the left-hand track return to the right-hand track via the second set of crossover switches (1-A/B).
- The bottom drawing shows the final position of the train.

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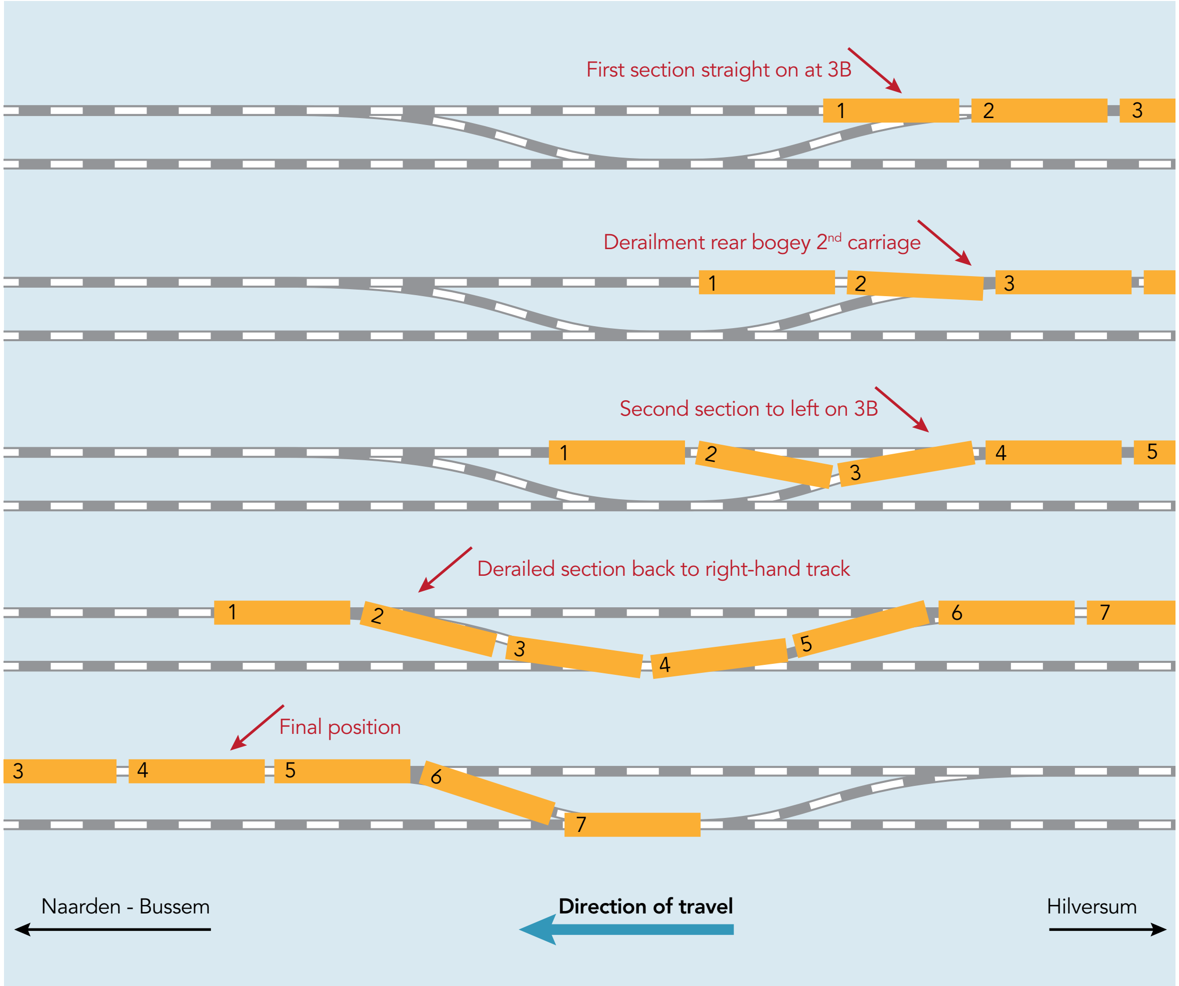

Figure 24: The course of movement of the train from the start of the derailment until reaching the final position. (represented schematically)

The photograph in figure 25, which was taken in the direction of travel of the train, shows the final situation. In the foreground, the crossover from the right-hand to the left-hand track is visible. Further away, we see the rear section of the derailed train, positioned on the left-hand track and the second set of crossover switches. The photograph also shows damage to the railway infrastructure (switches, rails and sleepers).

The consequences of the derailment were broadly speaking as follows:

- Of the passengers, two suffered minor injuries.
- The train suffered severe damage, particularly to the bogies and wheels. There was also damage to the carriages (because the bogies had adopted abnormal positions during the derailment), the bellows between the carriages and to a pantograph. Roughly estimated, the damage to the train amounted to approximately 225,000 euro (source: NS Reizigers).
- Severe damage was also caused to the railway infrastructure, which viewed from the direction of travel of the train started at switch 3B and continued as far as the final position adopted by the train. The damage related to the four switches and the tracks, the sleepers, the ballast bed and the catenary wires. Roughly estimated, the damage to the railway infrastructure amounted to about 2,200,000 euro (source: ProRail).

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Figure 25 The photograph shows the final situation (seen in the direction of travel of the train). In the foreground, the first crossover switch is visible, with in the background, the rear section of the train. (Source: Jan Barnier – Model Centre Hilversum)

C.1.3 Causes

In respect of the causes of the derailment, the Dutch Safety Board based its findings on its own observations during the investigation at the site, and the facts and materials that the parties involved provided on request. Given the available facts and materials, the Dutch Safety Board came to the following findings. For each finding, an indication is given of the grounds on which the finding is based. In that connection, reference is made to the following documents:

[Source 1] Report 'technical condition switch 3B' from ProRail, in which the findings are recorded from the investigation into switch 3B.
[Source 2] Report 14/140029/008 from Plurel, in which the findings are recorded from the investigation into the ring of the release mechanism of the right-hand locking rod of switch 3B.
[Source 3] Report NT/FS/MS/20140522/001 from NedTrain, in which the findings are recorded from the investigation into the wheel sets of the derailed train.
[Source 4] Report 14/140195/002 (version 0.1 draft) from Plurel, in which the findings are recorded from the investigation into the mechanical load that results from hitting an open blade.

Finding a
The train derailed because the right-hand switch blade of switch 3B shifted during the passage of the train after the release mechanism had failed.

Prior to the derailment, switch 3B was in the position to direct the train along the straight track, with the left-hand switch blade in locked position and the right-hand switch blade in open position (see figure 26). Source: the train safety system. The derailment was initiated when the release mechanism of the locking rod of the open right-hand blade failed. The failure of the rod meant that the front section of that switch blade worked loose, as a result of which it was able to shift into the locked position under the influence of the passing train (see figure 27). From that moment onwards, both switch blades were in the locked position so that the wheel sets which subsequently arrived at the switch were confronted with a narrowing of the track gauge and were forced to derail.

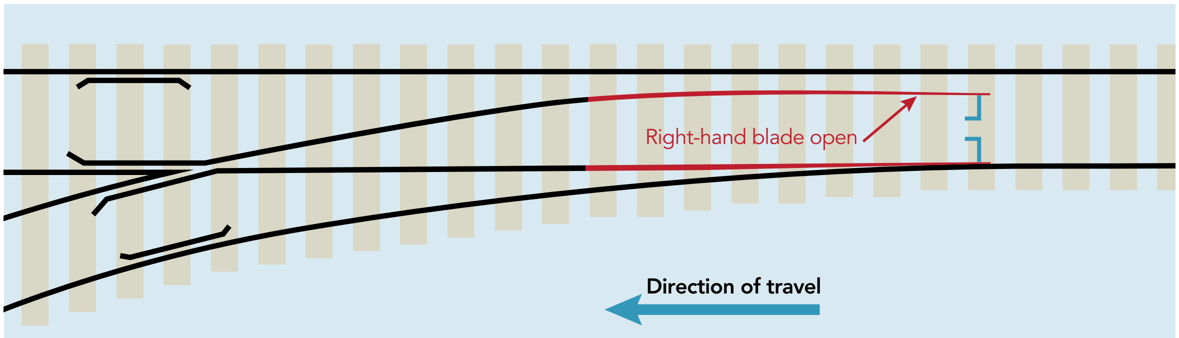

Figure 26: Prior to the derailment, switch 3B was in the setting for travel straight on.

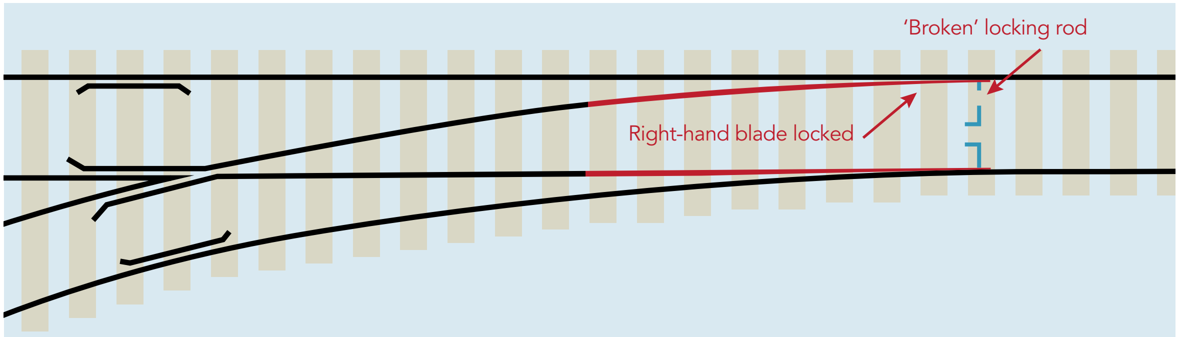

Figure 27: Due to the failure of the release mechanism, the right-hand switch blade was able to shift from open to locked position.

This sequence of events is based on the following arguments/reasoning:

- The damage caused to the railway infrastructure by the derailment started (from the point of view of the direction of travel of the train) at the position of switch 3B. Source: investigation at the scene.
- At switch 3B, the first three bogies travelled in straight direction, while the fourth and subsequent bogies were directed to the left. Source: video images from level crossing cameras.

- Even after the derailment, the point machine was still in the setting for travel straight on. The right-hand switch blade, which should then be in the open position, however, turned out to be in the locked position after the derailment. This combination was possible because the locking rod for the right-hand switch blade was 'broken' due to the failure of the release mechanism. Source: investigation at the scene.

Finding b
The release mechanism failed because the ring broke as a consequence of fatigue.

The release mechanism failed because a ring in this mechanism broke into two pieces. The photographs in figure 28 show the ring in question. The photograph on the left shows an example still intact while the two photographs on the right show the ring from switch 3B.

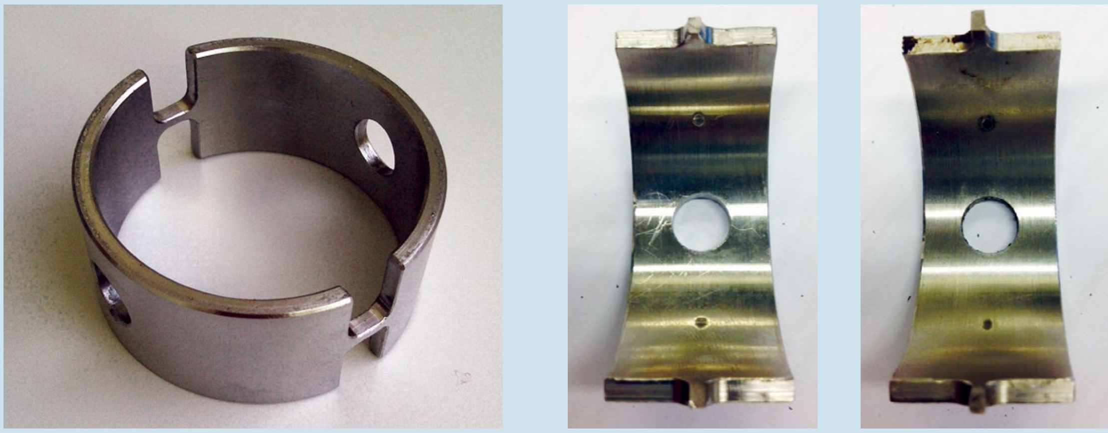

Figure 28: The photograph on the left shows an undamaged ring. The two photographs on the right show the ring from switch 3B, broken into two halves. (Source: ProRail)

The fracture surfaces (see the photographs in figure 29) reveal that the fractures are the result of fatigue [source 2]. Both fracture surfaces demonstrate so-called shell markings, which form a typical characteristic of a fatigue fracture. Both fracture surfaces also show no evidence of deformation (constriction) at the edges, which is as well characteristic of a fatigue fracture.

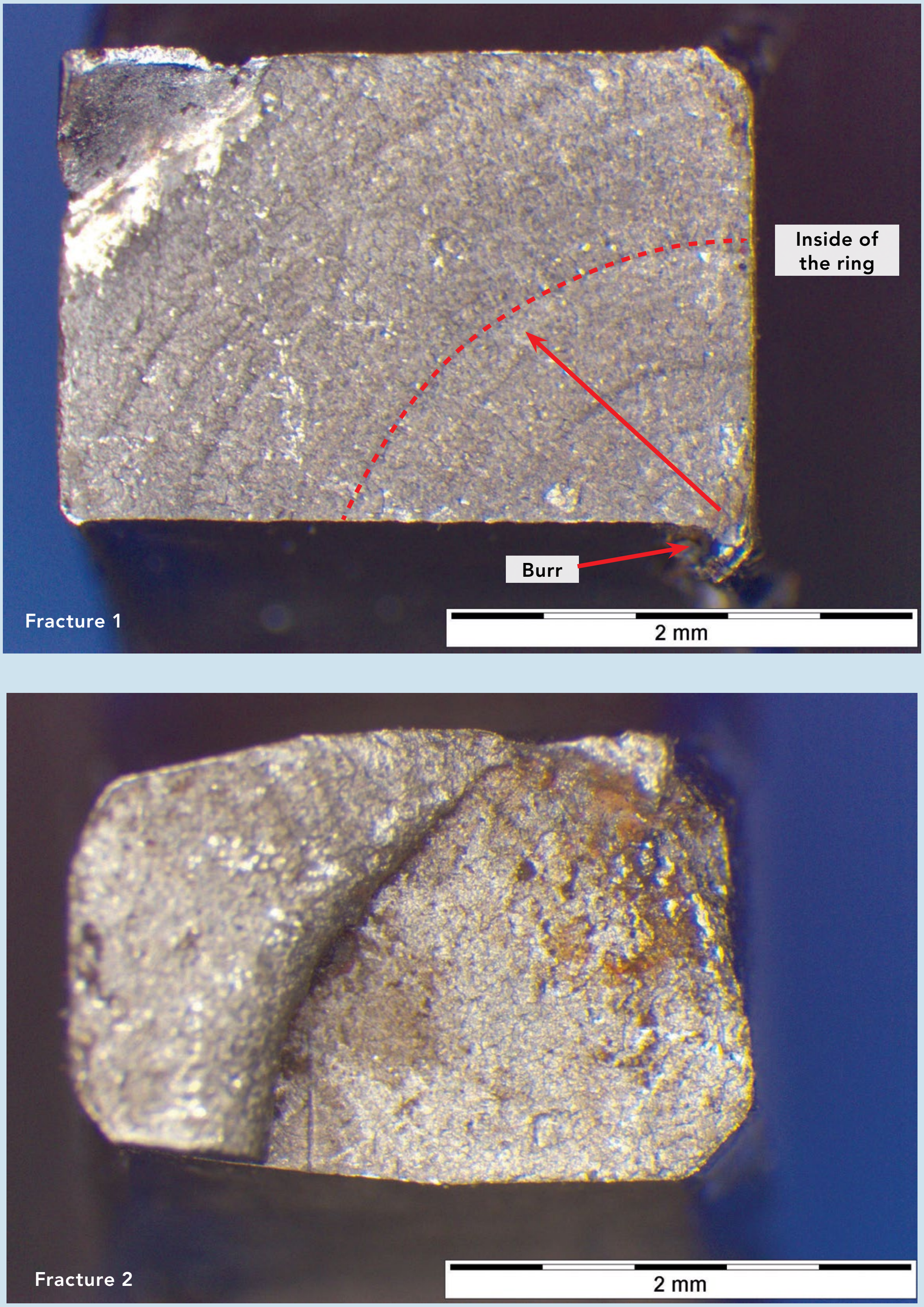

Figure 29: The photographs show the two fractures in the ring from switch 3B. The fracture surfaces demonstrate evidence of fatigue fractures. (Source: ProRail)

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Finding c
In the occurrence of these fatigue fractures, contributing factors were the repeated flange-back contact with the right-hand blade of switch 3B on the one hand (i) and the poor finishing of the ring on the other hand (ii).

i. *Flange-back contact with right-hand blade of switch 3B*
The right-hand blade of switch 3B showed considerable flange-back contact marks on the locking side, about halfway between the toe and the heel.

Figure 30: This photograph shows considerable flange-back contact marks on the right-hand switch blade of switch 3B. (Source: ProRail)

The flange-back contact marks reveal that the section in question of the switch blade, in the open position, was located so close to the stock rail that the inside edge of passing train wheels scraped along the open blade; so-called flange-back contact (see figure 31).

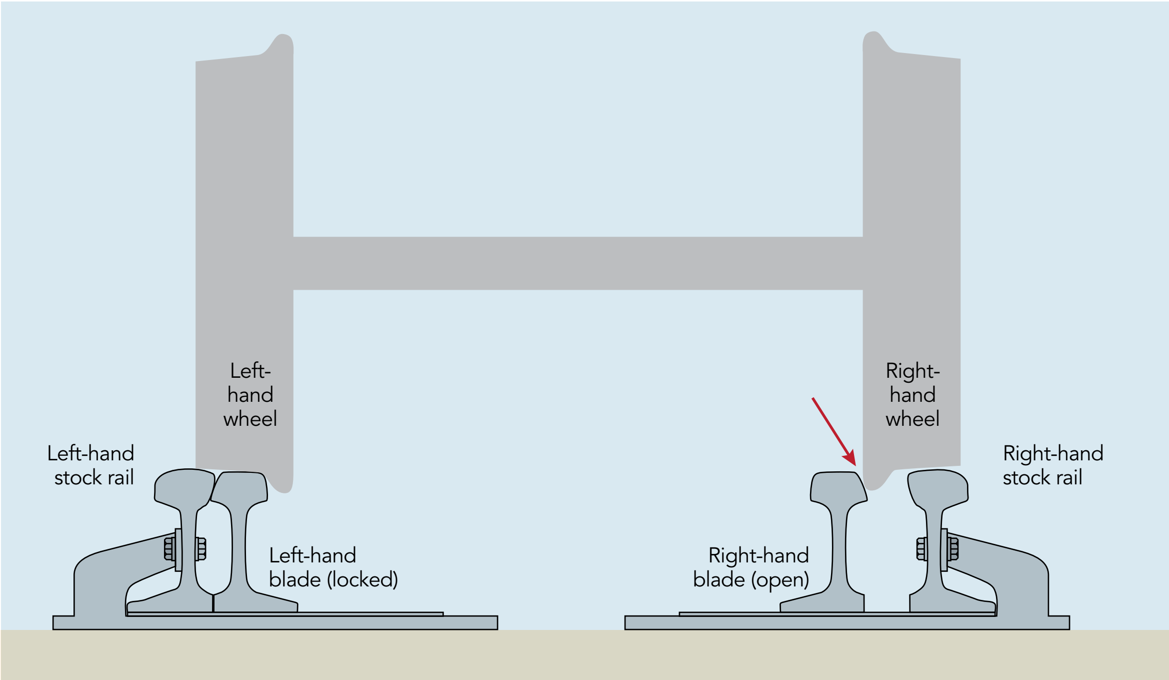

Figure 31: Flange-back contact marks occur when a switch blade in the open position is located so close to the stock rail that passing train wheels come into contact with it.

The size (depth) of the flange-back contact marks (1.3 mm) reveals ongoing flange-back contact. Whenever a switch blade is hit in this manner, it takes up an oscillating movement which results in dynamic forces in the locking rod. The more severe the flange-back contact, the more extreme the oscillating movement of the blade and the dynamic load on the locking rod will be. Given the above, the flange-back contact was accompanied by higher and more dynamic forces on the release mechanism (including the ring) than would occur during normal operation (without flange-back contact). Due to that increased load, the threshold load for fatigue effects was exceeded.

In this connection, reference could be made to an investigation ordered by ProRail in response to the derailment in Hilversum [Source 4]. In that investigation (see appendix F), the mechanical load that is applied on a switch mechanism when the open switch blade is hit by passing train wheels, was measured. The measurements reveal that flange-back contact is accompanied by a considerable increase in the dynamic load on the release mechanism. Without flange-back contact, the tensile force on the release mechanism ranges between approximately 0 and 3 kN and the number of changes equals the number of times that the blades are switched. With flange-back contact, the tensile force appeared to increase to approximately 5.5 kN, and the number of load changes to rise to 'several per passing train wheel'. These findings are also confirmed by an investigation into a derailment that took place in 2007 in Grayrigg in England (see appendix E under E.3). That investigation revealed that the forces on the point machine of the switch in question as a consequence of flange-back contacts rose to such an extent (to a factor of five) that the expected technical life of certain components was reduced from 'several decades' to 'a few weeks'.

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The fact that the number of shell markings on the fracture surfaces of the ring was such that the fracture must have been the result of at least approximately 15,000 load changes, confirms that blade hitting indeed played a relevant role in the failure of the ring. Such a number cannot be explained from the load changes coming from the regular blade switches. The ring in question had been installed in switch 3B for approximately eighteen months, and during this period, the blades were switched briefly approximately three times per day to the diverging track, which amounts to approximately 1,750 load changes.[33]

ii. *Poor finishing of the ring*
At both break links, the failed ring showed finishing defects (see the photographs in figure 32): at fracture 1, the defect concerns residual burrs, at fracture 2 it concerns too much and too rough grinding [source 2].

The fact that these non-conformities negatively influenced the fatigue strength of the ring is based on the following arguments:

- Generally speaking, sharp transitions (as in the case of a burr) and rough surfaces can initiate a fatigue fracture. In that sense, they can negatively influence the fatigue strength.
- The pattern of the shell markings in fracture 1 demonstrated that this fracture was initiated from the burr (see the photograph on the left in figure 29). Fracture 2 showed two-sided fatigue, which was on one side initiated from the rough grinding spot. [Source 2]

The available information provides no grounds to assume that in the breaking of the ring, besides the causes specified above, other elements played a role. In this connection, the following should be noted:

- The fracture surfaces of the ring show that the remainder of the fatigue fractures is relatively very small [Source 2]. This means that the force that eventually caused the ring to break was also relatively small.
- Following the derailment, no non-conformities were found on the wheel sets of the train other than those caused by the derailment. [Source 3, see also appendix F4]. In other words, there was no evidence of a bent or broken axle, a loose or shifted wheel tyre or similar non-conformities on the wheel sets of the train in question.

The finishing defects (residual burr and rough grinding spot) were able to occur because the production process of the rings involved 'manual deburring' and 'random final inspection'.[34]

33 The numbers stated are based on the information issued by ProRail, on request.
34 In response to questioning, the manufacturer (Bombardier) noted that the production process of the rings involved manual deburring (by scraping and/or grinding) and that the final inspection was carried out on a random sample basis (10% per batch).

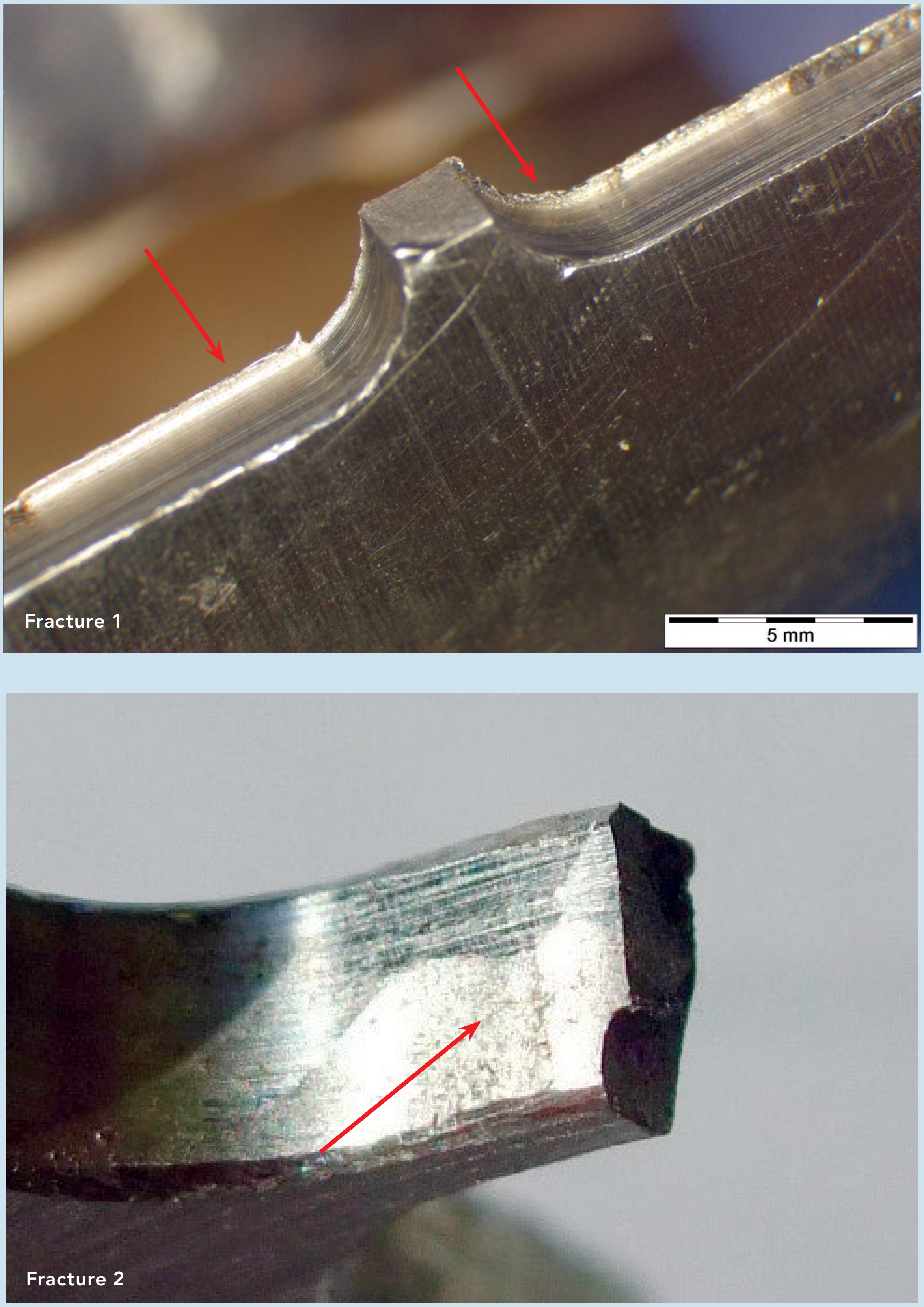

Figure 32: These photographs show the finishing defects demonstrated by the ring in switch 3B. Near break link 1, the defect concerns residual machining burrs, near break link 2 the defect concerns too much and too rough grinding. (Source: ProRail)

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Finding d
The right-hand blade of switch 3B was hit because of the fact that when switching the blade, the mid-section of the switch blade did not shift far enough away from the stock rail (in other words: because the free wheel clearance was larger than suitable for the geometry of the passing wheel sets). In the occurrence of flange-back contact, the position of the switch could have played a role in the sense that the switch in question was counter-curved and furthermore located relatively close to a level crossing.

When a train passes a switch, the inside of a train wheel can normally speaking only come into contact with the back of an open blade, if the free wheel clearance of the switch exceeds the sum of the inside gauge and the flange thickness of the opposite wheel (see figure 33).

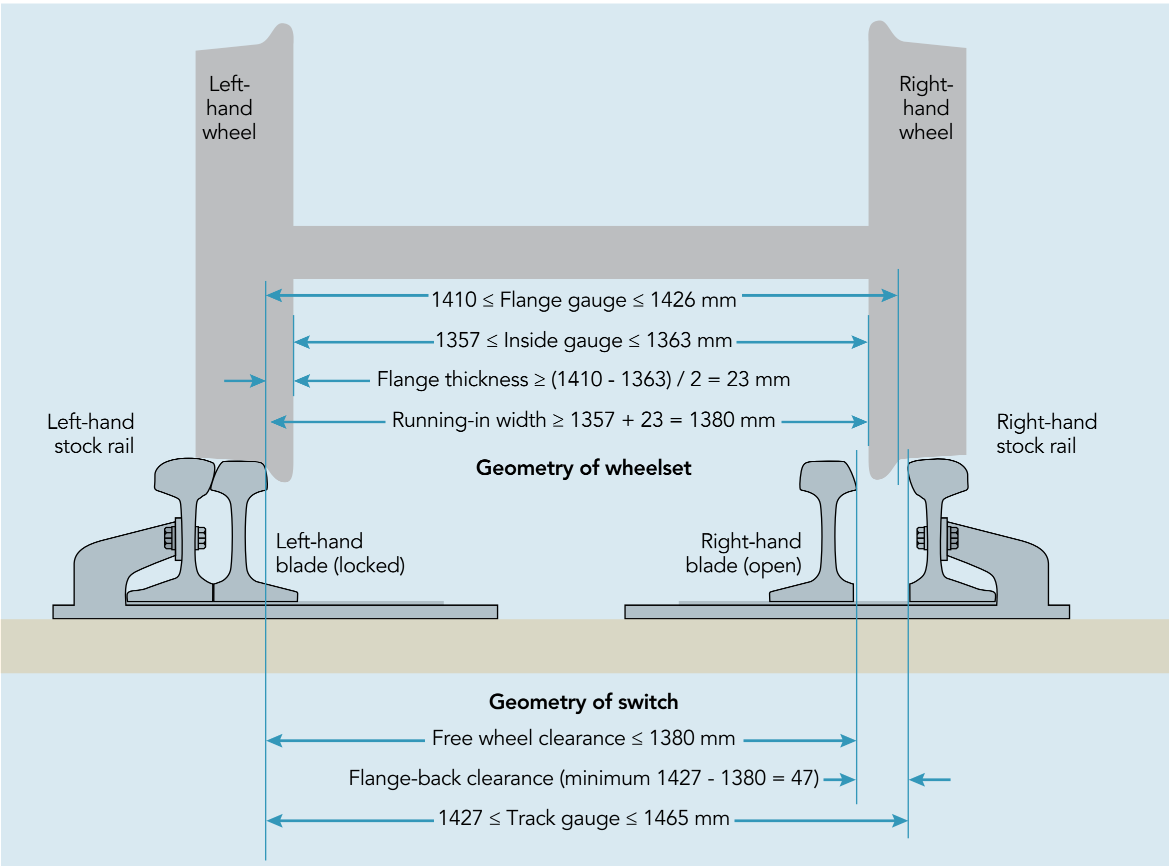

Figure 33: This illustration shows the relationship between the inside gauge and the flange thickness of a wheel set on the one hand and the free wheel clearance of a switch on the other hand.

According to TSI-INF, the free wheel clearance in a switch must be less than 1380 mm. Only when demonstrated that the switch (including point machine) can withstand blade hitting, this standard may be deviated from. This standard for the free wheel clearance is matched to the regulations for the geometry of wheel sets: the TSI-RS demands that on wheel sets, the inside gauge is more than 1357 mm and the flange thickness more than 23 mm (as a consequence of which the sum of the two distances is at least 1380 mm).

The above implies that at switch 3B, the free wheel clearance must have been wider than 1380 mm, or that on the passing rolling stock, there must have been numerous wheel sets which did not comply with the regulations for the inside gauge and/or flange thickness. There are no grounds to assume that in a large proportion of the wheel sets that passed switch 3B, the inside gauge and/or flange thickness did not comply with the regulations. However, there are indeed grounds to assume that prior to the derailment, the free wheel clearance of switch 3B was regularly larger than the European standard (1380 mm). In measurements carried out on switch 3B following the derailment, it emerged that immediately after moving the right-hand switch blade into the open position the free wheel clearance was considerably more than 1380 mm; the measured value in question, which fluctuated somewhat during the various measurements, rose to as much as 1424 mm. [Source 1]. Video images taken by a video inspection train which passed this switch some time before the derailment, reveal that the front wheel set of the inspection train had hit the right-hand switch blade (which was in the open position), and that subsequently, the flange-back clearance was approximately 35 mm. This latter value implies, in combination with the track gauge at the site (approximately 1437 mm) that after the front wheel set of the video recording train had passed, the free wheel clearance must have been approximately 1402 mm.[35]

Furthermore, in respect of the location of the switch, the following should be noted:

- Switch 3B was an ordinary switch, originally with a radius of deflection of 195 m, but which was subsequently bent back with a radius of 3150 m (as a consequence of which the radius of deflection eventually amounted to 208 m) [source 1]. The fact that the switch was counter-curved implies that at the site in question the track curved to the right, with a radius of approximately 3150 m). As a consequence, passing trains will have had the tendency[36] to 'go towards the outside bend', meaning that the right-hand wheels ran closer to the open right-hand switch blade.
- Switch 3B was located adjacent to a level crossing of the type Harmelen, and the distance between the front of the switch and the level crossing was approximately just 3 m. Measurements carried out immediately following the accident revealed that the track gauge both at the level crossing and at the front of the switch was approximately 1440 mm, but that this rose to approximately 1446 mm in the section of track in between. This relatively considerable change in track gauge (approximately 6 mm over a distance of just approximately 3 m) possibly[37] led to additional lateral shifts by the passing bogies, at the site of the switch.

35 It is possible that during the recording, the switch blade was still oscillating (as a result of the flange-back contact) as a consequence of which the flange-back clearance on the images was narrower or wider than the actual flange-back clearance in a static position. The value for the free wheel clearance calculated on the basis of the image is therefore not entirely reliable.
36 The effect was probably limited because of the ratio between radius of curvature/train speed (3150 m and approximately. 50 km/hour).
37 This effect can only be expected if the change in track gauge was asymmetrical.

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Finding e

The free wheel clearance of switch 3B was so large that the right-hand switch blade in the open position was hit because the parts that support the movement of the right-hand switch blade were worn and some other parts did not comply with the regulations.

In measurements carried out after the derailment at switch 3B, it emerged that the mid-section of the switch blade when moving from the locked to the open position remained too close to the stock rail (see the photographs in figure 34). On the left-hand photograph, the switch blade is still locked, on the middle photograph the movement has been half completed, and on the right-hand photograph the open position has been achieved. Because during movement the mid-section of the switch blade lagged behind, the free wheel clearance was too large. During a series of measurements, values were measured ranging from 1389 to 1424 mm. [Source 1].

Figure 34: These photographs show the movement of the right-hand switch blade of switch 3B, from locked to open position (see the yellow arrow) whereby an oversized free wheel clearance arises (see red arrow) because the switch blade remains too close to the stock rail in the top of the photograph. (Source: ProRail)

To reduce the friction resistance when moving the switch blades, switch 3B was equipped with an Ekos-V system (see figure 35). An Ekos-V system is a mechanism that is fitted below the mid-section of the switch blade. This system – which is attached between two sleepers – consists of two horizontal rollers mounted on a spring construction. The system is adjusted in such a way that the top of the rollers protrudes approximately 1 mm above the slide chairs. As a result, at the mid-section, the underside of the switch blade rests on the rollers, and not on the slide chairs. As a consequence the mid-section of the switch blade experiences considerably less resistance during movement (than would be the case when sliding across the slide chairs). When train wheels travel over the switch blade, the rollers are forced downwards, so that the bottom of the switch blade temporarily rests on the slide chairs.

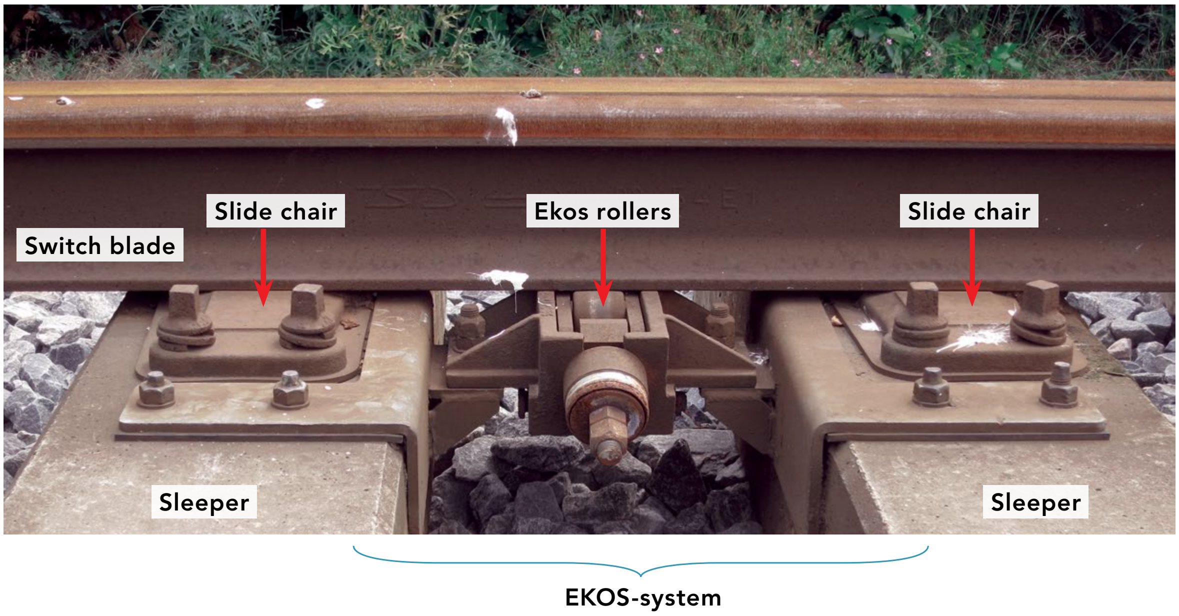


Figure 35: The photograph shows the Ekos-V system of switch 3B.

The Ekos-V system of the right-hand switch blade of switch 3B proved to be so badly worn that the rollers no longer protruded above the slide chairs [Source 1]. This situation must have continued for some time, because the slide chairs themselves also showed considerable wear (see the photographs in figure 36). The lower left-hand photograph shows the worn Ekos-V system. The lower middle photograph shows the underside of the right-hand switch blade; this photograph shows that the frame and the rollers of the Ekos-V system are stamped into the underside of the switch blade. The lower right-hand photograph shows one of the slide chairs; this photograph shows that – both below the switch blade and below the stock rail – the slide chair is severely worn. Due to the fact that the Ekos-V system no longer functioned, the mid-section of the right-hand switch blade, when moving to the open position, must have remained so close to the stock rail, that it could be run hit by the inside of the passing train wheels.

The technical investigation into switch 3B [see source 1] revealed the following further non-conformities:

- On the right-hand switch blade, the first two blade supports (as viewed from the toe) were approximately 4 mm shorter than they should have been according to the design drawing. As a consequence, the radius of the right-hand switch blade in the mid-section was considerably smaller than intended (approximately R = 160 m instead of R = 208 m).
- On the right-hand stock rail a number (in total 8 of the 17) horizontal bolt fastenings (with which the stock rail was attached to the slide chairs) were loose.

- The stroke of the point machine was 4 mm shorter than it should have been according to the specifications (127 mm instead of 131 mm).
- These non-conformities (in particular the first and last) are also expected to have contributed to the already mentioned excessive free wheel clearance (and as a result the occurrence of the flange-back contacts).

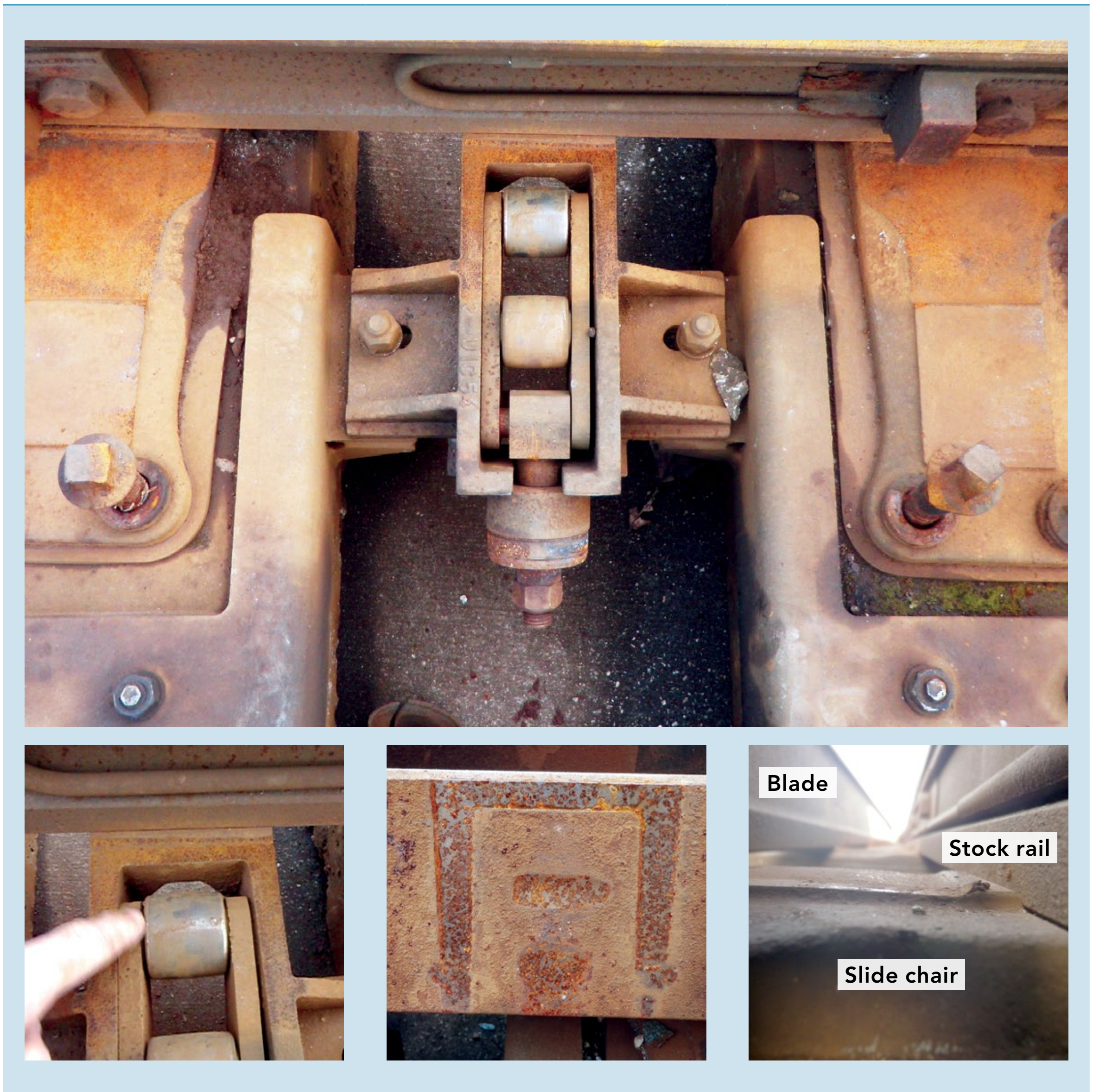


Figure 36: These photographs show the worn parts that support the right-hand switch blade of switch 3B. De upper photograph shows the top view of the Ekos-V system. The lower left-hand photograph shows the wear on the rollers. The lower middle photograph shows the stamp of the Ekos-V system on the underside of the blade. The lower right-hand photograph shows one of the worn slide chairs. (Source: ProRail)

C.2 Previous problems with EBI switch

C.2.1 Introduction

In 2008, a number of incidents occurred involving EBI switches in use in the Netherlands. At five switches, the ring in the release mechanism appeared to be damaged, while at two other switches, the attachment of the rod head proved faulty. The relevance of these incidents to this investigation relates to the fact that – in hindsight – in these incidents, the phenomenon of flange-black contact had probably played a role as well.

C.2.2 Incidents

Rings

In March 2008, a maintenance contractor discovered a damaged ring in the release mechanism at switch (239-A) in Arnhem-Velperbroek. Further investigation revealed that the switch in question had not been run through. It was also revealed that in four other switches (233, 235 A/B, 271 and 1035 A/B) in the same area, the ring was damaged, and that in those cases, too, there had been no run-through events. The rings at the time had just one break link instead of two. The damage discovered related to the fact that the break link was broken (see the photograph in figure 37). In all five cases, the broken ring was still in position despite the fracture, so that the release mechanism had not been activated effectively.

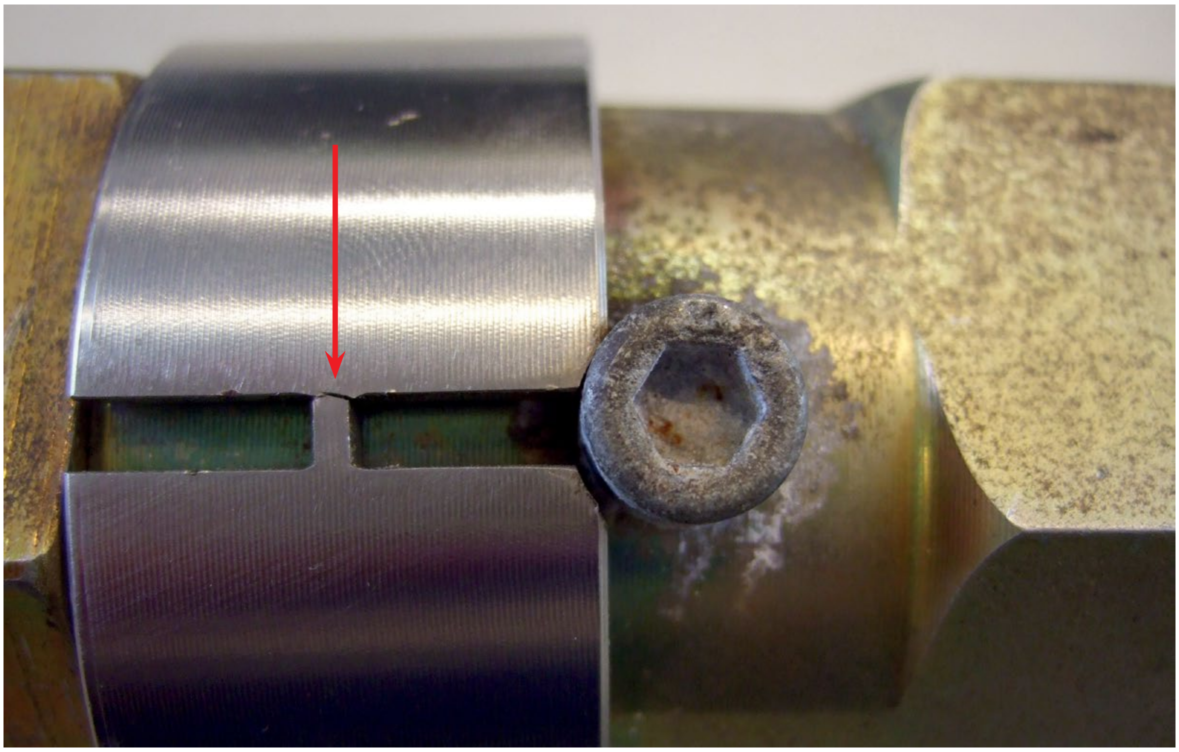


Figure 37: This photograph shows one of the damaged rings discovered in 2008. The arrow points to a fracture in the break link. (Source: ProRail)

Both Bombardier and DeltaRail (on behalf of ProRail) carried out investigations into these incidents. The damaged rings were further investigated and tests were carried out to measure the breaking strength of the rings. In brief, the findings were as follows:

- In a number of the rings examined by Bombardier (from switch 233 and 235), the break links had been deformed. In the judgement of Bombardier, the deformations were probably the result of incorrect installation or incorrect maintenance of the locking rod in question.
- On the broken ring from switch 239-A (examined by DeltaRail), the fracture surface showed the characteristics of a fatigue fracture. According to DeltaRail, there were no indications that this fracture was due to incorrect installation or maintenance.
- Tensile strength tests revealed that the breaking strength (of unbroken examples) of the rings, which according to the specifications from Bombardier should have been 38 plus or minus 5 kN, varied between 31.4 and 77.4 kN.

On the basis of the investigation results, Bombardier concluded at the time that the fractures had probably been caused by incorrect installation or maintenance of the locking rods. For that reason, the decision was made to adjust the design of the ring in such a way that the incorrect practice could no longer occur. To ensure that the breaking strength of the ring remained within the intended boundaries, the rings were designed with two break links instead of one. It was also decided to round the corners of the break links (which was not the case in the original design). The rounding of the corners was intended to make the rings less susceptible to fatigue. The photographs below show the original (left) and modified (right) ring design. On the instructions of ProRail, the modified ring design went through a series of fatigue tests at the time, and the results revealed no grounds for further alterations.[38]

Figure 38: The left-hand photograph shows a ring of the original type (with a single break link and square corners); the right-hand photograph shows the modified version (with two break links and rounded corners. (Source: ProRail)

Rod heads

In mid-2008, problems occurred at two switches with the attachment of the rod head to the locking rod. In the design at the time, the attachment of the rod heads to the cylindrical section of the locking rod consisted of a threaded connection (see figure 39).

38 The tests are described in report 90529 from DeltaRail.

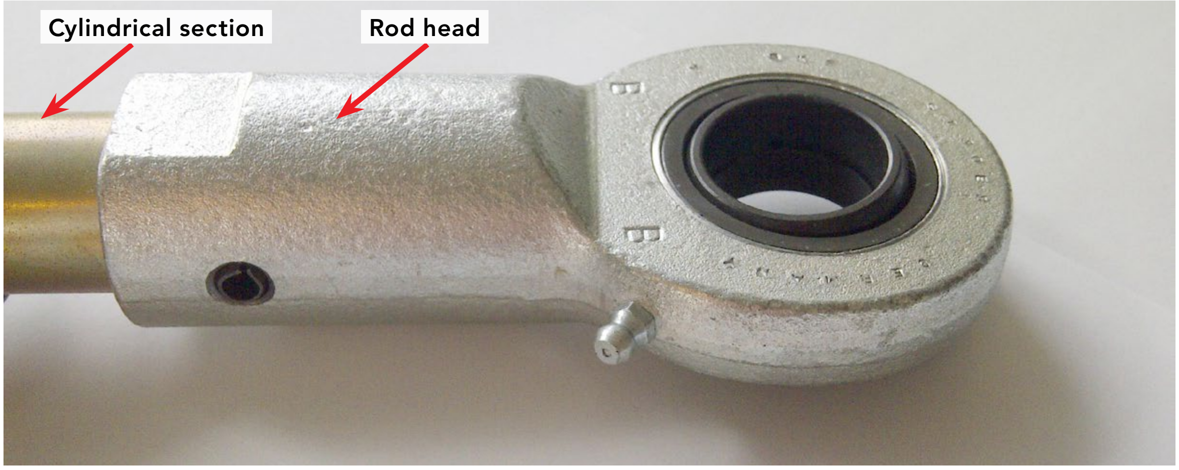


Figure 39: This photograph shows the original design of the rod head whereby the rod head was attached to the cylindrical section with a threaded connection. (Source: ProRail)

In the first incident, which occurred in April 2008 at switch 1373-A in Kijfhoek, the threaded connection demonstrated excessive wear and serious corrosion (see the left-hand photograph in figure 40). In the second incident, which occurred in August 2008 at switch 215 at Herfte junction, the threaded connection of the rod head had become loose (see right-hand photograph in figure 40). In both cases, the tension pin (intended to prevent unwanted twisting) had fractured.

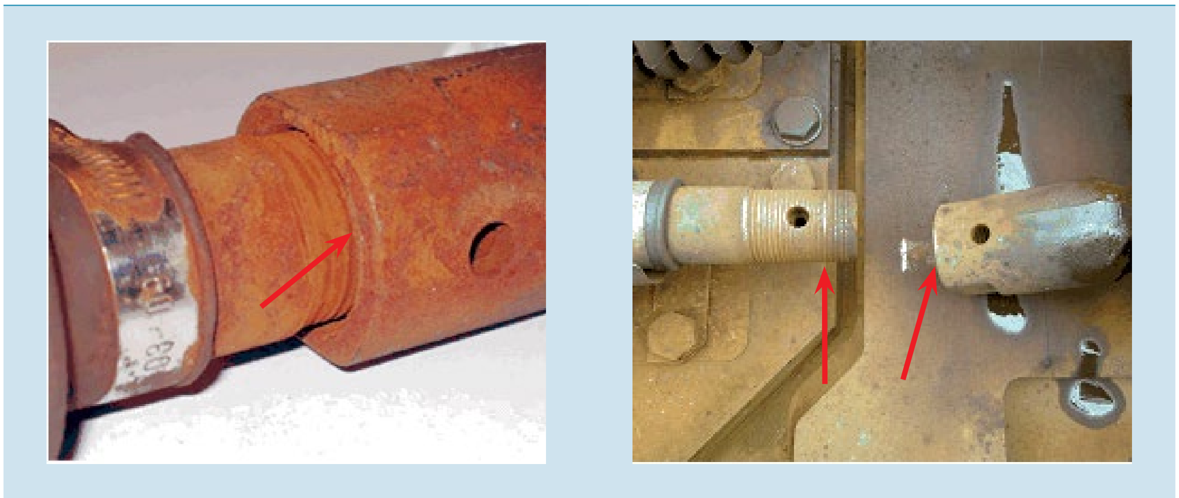
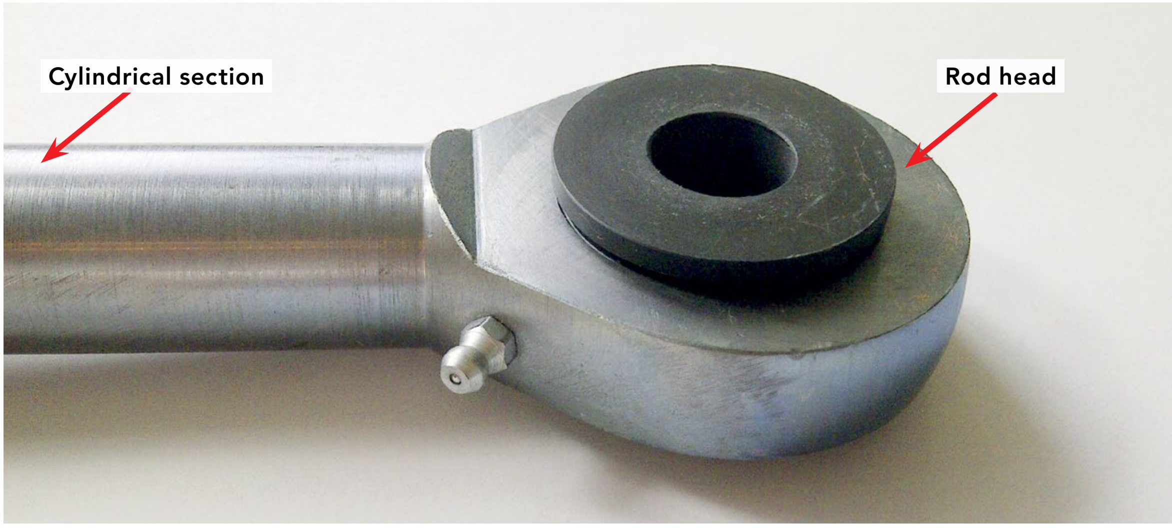


Figure 40: These photographs show the threaded connection of both damaged rod heads from 2008. (Source: Bombardier)

In the case of both incidents, the problem emerged because the switch in question could not be brought 'in control', and because the problem had not led to a derailment.

Bombardier, in cooperation with ProRail, carried out detailed investigations at the time into these incidents. Not only the damaged rod heads were examined, but also various tests were carried out on undamaged examples. These included vibration tests, corrosion tests and fatigue tests. On the basis of the investigation results, Bombardier reached the conclusion that vibrations and corrosion played an important role in the occurrence of the wear on the threaded connection of the rod head. On the basis of the vibration tests, it was further concluded that the wear could not be explained if the rod heads were only exposed to vibrations which normally occur in switches. As a consequence, vibration tests were carried out on one of the switches in question (switch 215 at Herfte junction) also. Using sensors, during the investigation, measurements were made to determine the acceleration experienced by the switch blades and locking rods when a train passed the switch. The measurements were carried out over a period of approximately two weeks, and during that period, approximately two thousand trains passed the switch. The measurement results revealed that at the switch in question, the open blade was hit. It also emerged that as a result of the flange-back contact, an oscillating movement arose, which was accompanied by severe movements (also in a vertical direction), of the toe of the switch blade.

On the basis of these investigation results, Bombardier decided at the time to adjust the design of the rod heads in the sense that both components which were originally joined together by a threaded connection (and tension pin) were manufactured in single section. (see figure 41).



Figuur 41: This photograph shows the modified design of the rod head whereby the head and the cylindrical section are manufactured in single section.(Source: ProRail)

APPENDIX D

MANAGEMENT OF THE DUTCH RAILWAY NETWORK

MANAGEMENT OF THE DUTCH RAILWAY NETWORK

D.1 History

Originally, the construction and maintenance of the railway infrastructure and its use (passenger and goods transport by rail) were the responsibility of a single national railway company: the NV Nederlandse Spoorwegen (NS). At the time, NS was also involved in the design and manufacture of the rolling stock and the infrastructure. Between 1995 and 2005, the national railway company was split up into a series of business units. This unbundling related to the EU Directives according to which management and use of the railway infrastructure had to be separated. During that process, the management of the railway infrastructure was for several years entrusted to NS Railinfrabeheer. In around 2005, that organisation was absorbed in today's ProRail. There are now two railway managers, namely ProRail and KeyRail, and a number of rail operators, including NS Reizigers and DB Schenker, respectively the largest passenger and goods operator.

D.2 Distribution of roles and responsibilities

The Railways Act specifies that the Minster of Infrastructure and the Environment is responsible for the construction and management of the railway infrastructure. In respect of the management of the railways, this responsibility includes the sound regulation of safety by means of legislation, the issuing of permits and supervision.

In accordance with the European Interoperability Directive, the Railways Act specifies that:

- the management of the railway infrastructure must be entrusted to a manager on the basis of a concession;
- the manager must have a safety permit, which may only be issued if the manager operates a safety management system (SMS) that complies with the European Railway Safety Directive, and is operationalised in such a way that the railway infrastructure can be safely managed and used;
- the concession is subject to requirements to guarantee that the railway manager for example analyses safety risks and manages those risks sufficiently with suitable measures.

On the basis of the above described provisions in the Railways Act, the Minster awarded the management of the railway infrastructure in a concession to ProRail. The current management concession was issued for the period 2005-2015. The management concession includes a duty of care. The essence of that duty is that among other points, ProRail must ensure 'that the main railway network can be travelled safely and efficiently' and that 'the safety risks are analysed and sufficiently managed with suitable measures'. This duty of care refers back to the requirements contained in the Railways Act on the content of the concession, but provides no further detailing. The next management concession (for the period 2015-2025) will also be awarded to ProRail.

D.3 Railway maintenance

ProRail has opted to outsource the actual maintenance of the railway infrastructure to contractors. In the initial years, maintenance was outsourced internally. There were five regions and three contractors (BAM Rail, Strukton Rail and Volker Rail). Considerable changes have occurred in the tendering process for maintenance over the past years. Today, new maintenance contracts are subject to public tender with a contract period of 5 or 10 years[39]; the railway network has been divided into more contract areas; and a fourth railway contractor has joined the initial three (Asset Rail).

Until 2008, ProRail outsourced railway maintenance on the basis of output process contracts (OPCs). In this type of contract, the subcontractor has a best-efforts obligation: ProRail prescribes the maintenance work to be undertaken. Since 2008, ProRail switches to the so-called performance-based maintenance (PGO) contracts. PGO contracts lay down the quality requirements that the railway infrastructure must fulfil in terms of availability, reliability, sustainability and safety. The contractor then has a certain degree of freedom in respect of the maintenance activities to be undertaken to achieve that level of quality. In this way, contractors are put into competition with each other for the execution of maintenance. The intention is to make railway maintenance cheaper as well as more efficient. Although performance-based maintenance is also employed in other sectors, it is far less common practice in the railway world, outside the Netherlands. In that sense, the Netherlands is a pioneer. Approximately one-third of all contract areas have now been outsourced on the basis of PGO contracts. This process is subject to a transition phase.

D.4 Construction and replacement

For the construction and replacement of the railway infrastructure, ProRail purchases parts (such as switches and point machines) from specialist manufacturers. Switch 3B in Hilversum, for example, was assembled by Wisselbouw Nederland and the EBI switch, with which switch 3B was equipped, was produced by Bombardier.

For large-scale new-building projects (such as the Betuwe route) and the introduction of a new railway safety system, the Railways Act demands a First Commissioning Permit (vergunning voor ingebruikname - VVI) on the basis of European inspection. This applies

39 The PGO 2.0 contract has a duration of 5 years, the PGO 3.0 a duration of 10 years.

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also for rails, sleepers and their fixings.[40] For all other situations, no European inspection or First Commissioning Permit is required,[41] but for the introduction of new railway objects, ProRail does operate an admission procedure, the so-called Permission for Use (toestemming voor gebruik - TVG).

D.5 Requirements on switches

In respect of the railway infrastructure itself, government legislation takes the form of the Railways Act and the accompanying regulations and decrees. These refer to the European Directives, specifications (Technical Specifications on Interoperability – TSI) and standards. The regulations also contain a number of functional and technical specifications for switches. These are contained in the TSI infrastructure. For certain geometric characteristics, including the free wheel clearance, specific values are laid down. A further requirement is that the switch operation must be lockable when the switch is to be passed at a speed of more than 40 km per hour.

The TSI infrastructure applies only to infrastructure elements in use or put into use since the introduction of the TSI on 1 June 2011. For older objects, the requirements that were in place at the moment of introduction of the TSI apply, that were laid down in the Network Infrastructure Regulations. These regulations at the time did include requirements on specific geometric values (dimensions) but no particular requirements were imposed on the free wheel clearance.

D.6 Supervision

Supervision of compliance with railway legislation is the responsibility of the Human Environment and Transport Inspectorate (ILT). The ILT fulfils this task in the form of audits, inspections and accident investigations.

Audits
ProRail operates a safety management system (SMS) and part of that system is a broad-based risk inventory and evaluation (RI&E). In the framework of the issuing of the safety permit, the SMS of ProRail is assessed periodically (every 3 years) by the ILT. Such assessments are undertaken at system level. Furthermore, annual audits are carried out that focus more specifically on certain elements of the SMS or particular subjects.

Inspections and theme studies
The ILT also carries out targeted inspections whereby on a random basis, the maintenance condition of a train, the administration of a railway company and the condition of railway objects, for example, are investigated. Broad-based theme studies are also carried out. A recent theme study by the ILT involves the study into the effect of performance-based

40 These components are designated in the TSI-INF as so-called interoperability parts.
41 In the majority of other European Member States, there are no government admission procedures for parts such as point machines, with the exception of Germany (in the form of the so-called EBA-Prüfung).

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maintenance contracts on the safe usability of the railway system. The results of this study were presented to the Dutch Lower Chamber on 21 February 2014. The ILT concludes that overall, PGO contracts result in more flexible standards than OPC contracts, and that management of safety must be given a more prominent position in the tendering and execution of maintenance. The incomplete availability of object information and the limited insight of ProRail into the actual state of maintenance are causes for concern at ILT. Furthermore, the ILT also recently ordered a study into the physical quality of the national railway infrastructure.[42]

Accident investigations
Railway accidents, from a certain degree of seriousness, are investigated by the ILT. Over the past ten years, the ILT has investigated seven accidents, whereby the direct cause was partially attributable to a shortcoming in the railway infrastructure.[43] None of these accidents were fatal and all involved derailments. One of the accidents that shows many similarities with the train derailment in Hilversum was the accident in 2006 in Dordrecht.

D.7 Developments in government policy

Currently, railway policy is subject to a transition process to improve the reliability of the railways (and hence its attractiveness to passengers) and to reduce costs at the same time. In this connection, the parliamentary inquiry 'Onderhoud en innovatie spoor' ('Railway maintenance and innovation') by the Kuiken Committee played an important role.[44]

In 2012, one of the conclusions of the committee was that there were concerns about (maintaining) the quality of the railway infrastructure, and that in that connection, the Minister needed to exercise stricter management and control. Following on from the report, the Ministry of Infrastructure and the Environment drew up the Long-Term Railway Agenda (Lange Termijn Spoor Agenda - LTSA). This agenda expresses the government's policy ambitions for the long term.

New management concession for ProRail
The management concession to ProRail is an important tool for achieving policy objectives. At present, a new management concession for the period 2015-2025 is being prepared. In the new management concession, which is also due to be awarded to ProRail, the ambition is clearly expressed that the quality of rail traffic (as a transport product) must be improved. In addition, ProRail is set the assignment of professionalising its tasks, for example in respect of maintenance of the infrastructure, by means of more effective outsourcing. In that process, as is the case in the current concession, ProRail is called to account on the basis of performance indicators. It is noted that those indicators

42 The results are described in outline in paragraph D7.
43 Appendix E (in subsection 2) provides a concise description of these accidents.
44 On 29 March 2011, the Dutch Lower Chamber agreed to the proposal from the permanent committee for Infrastructure and the Environment to carry out an investigation into the Dutch Railway System. The Kuiken Committee published its report on 16 February 2012. The Parliamentary Inquiry into Railway Maintenance and Innovation was intended to contribute to an efficient railway system in general and to promote innovation wherever meaningful.

relate to the availability of network capacity and the punctuality of train traffic, but not to the safe usability of the network. The difference between this and the current concession is that the new indicators are even more specifically aimed at passenger satisfaction, which depends above all on the degree to which train service disruptions are reduced. Another important change arising from the recommendations from the Kuiken Committee is that in the new concession, the Minister´s control over railway management is reinforced.

Baseline measurement physical quality railway infrastructure
Partly in response to a recommendation from the committee, the physical quality of the national railway infrastructure was inventorised in 2013. During this zero measurement, undertaken by the ILT, more than 2500 railway objects were inspected and assessed according to a selected set of ProRail maintenance standards. The inspected objects were located in five different contract areas of which the contract area Eemland (in which switch 3B in Hilversum is included) was one. The baseline measurement revealed that 15% of the infrastructure failed to comply with the ProRail maintenance standards. The percentage not in compliance reflects considerable variations between the various contract areas and between the types of objects. The rejection percentage for switches was on average 23% but in one of the maintenance areas in fact totalled 68%. In its report, the ILT pointed out that in respect of the objects in relation to which maintenance failed to comply with the ProRail regulations, it is not possible to state that safety was at risk. ProRail has assured to take adequate measures. The ILT will supervise implementation of those measures.

The baseline measurement provides an overall picture of the condition of the railway infrastructure. In respect of switches, the picture is worrying. However, the baseline measurement provides no specific information about aspects which played a role in the occurrence of the derailment in Hilversum. This is because the physical quality was assessed according to a selection of the management standards employed by ProRail. Those aspects for which no ProRail regulations exist, like blade hitting, were as a result not considered.[45]

The condition of the railway infrastructure will be inventorised every 5 years, so that he Minister is able to monitor quality in the longer term.

Reassessment of the policy framework for railway safety
The current policy framework for railway safety is laid down in the Third Railway Safety Framework Memorandum (2010-2020). An interim evaluation of that policy is planned for 2015. The Ministry of Infrastructure and the Environment will use that evaluation moment to reassess the policy vision. In that connection, the project entitled Rail Safety Innovation Impulse is currently underway. This project involves the extended exchange of ideas between the Ministry, the railway companies and the organisations representing the interests of public transport passengers, whereby one of the subjects of discussion will be how the interests of safety should be considered against the other interests (such as capacity and punctuality). The intention is to implement this reconsideration in 2015 (by revising the Framework Memorandum or by issuing a policy letter).

45 Subjects like the free wheel clearance and the maintenance condition of Ekos-V rollers and slide chairs, which played a role in the occurrence of the derailment in Hilversum, were not included in the study.

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APPENDIX E

COMPARABLE ACCIDENTS

APPENDIX E

COMPARABLE ACCIDENTS

E.1 Introduction

The accident in Hilversum involved a derailment, the direct cause of which – as described in chapter 3 and appendix C.1 is – consisted of a defect in an object in the railway network (in this case a switch). The first section of this appendix (E.2) provides an overview of other accidents of this type, which have occurred over the past ten years in the Netherlands. This section describes seven derailments, one of which also involved a defect in a switch. In the second section of this appendix (E.3), foreign derailments are described, which were also the consequence of a switch defect. All four cases led to fatalities and were caused by a defect that was the result of poor maintenance.

E.2 Derailments due to infrastructure defects in the Netherlands

Over the past ten years, seven accidents have occurred on the main railway network in the Netherlands, whereby a defect in the railway infrastructure contributed to the direct cause. None of these accidents led to fatalities, and all were derailments.

The accidents concern the following derailments:

- In 2011, a goods train derailed on the Caland bridge in Rotterdam as a consequence of a faulty repair to the bridge structure.
- In 2009, an empty passenger train derailed in Zwolle, (partly) as a consequence of the poor attachment of rails to the sleepers.
- In 2007, a goods train derailed in Duiven, partly as a consequence of a deviation in the positioning of the track.
- In 2006, passenger trains derailed at two locations (Zwammerdam and Landgraaf) due to bending of the rails as a result of high outdoor temperatures (buckling);
- In 2006, a goods train derailed in Dordrecht due to the poor maintenance condition of a switch.
- In 2005, a passenger train derailed in Amsterdam, partly because the straight section of track between two switches was too short.

In particular the derailment in 2006 in Dordrecht demonstrates considerable similarities to the derailment in Hilversum. Here, too, the derailment took place at a switch, and the direct cause was a defective switch. In this case, the defect was serious wear (crumbling) of the switch blade in question. An investigation by the Transport, Public Works and Water Management Inspectorate revealed that the maintenance contractor responsible had observed six months previously that the blade in question was in need of repair or replacement. Other switches in the railway yard were also shown to be in such a poor maintenance condition that rejection standards (base and safety values) were exceeded. At the time, the Inspectorate further concluded that ProRail had insufficient insight into the technical condition (safety) of the railway infrastructure. The Inspectorate further expressed considerable concerns, in particular about the inadequate signalling of potentially hazardous situations, the failure to always guarantee the safe usability of the infrastructure and the quality of the relationship between ProRail and its subcontractors. At the time, the Inspectorate ordered ProRail to take measures both to correct the overdue maintenance and to rectify the identified points of concern.

E.3 Derailments due to infrastructure defects abroad

Over the past fifteen years, in the countries surrounding ours, four serious derailments (with fatalities) have occurred, that – just as was the case with the derailment in Hilversum – were caused by a defect in the track. The four derailments are described briefly below.

Hatfield – England (2000)
On 17 October 2000, near Hatfield in England, a passenger train derailed resulting in the death of four passengers and dozens of injuries. At the time of the derailment, the train was travelling at a speed of approximately 185 km/hour. The investigation[46] revealed that the direct cause of the derailment was the failure of a rail as a consequence of fatigue cracks in the rail head. The fatigue problem had been known prior to the accident, and the contractor was planning the replacement of the rail; however, the process was extremely slow. Following the accident, it emerged that comparable fatigue problems were also present on a large scale, on other track sections. It also became clear that the railway infrastructure manager (Railtrack) had only very limited technical expertise at its disposal and had insufficient insight into the technical condition or maintenance condition of the railway infrastructure. This accident was the primary reason for the partial renationalisation of railway management (the transfer from Railtrack to Network Rail) in England.

Potters Bar – England (2002)
On 10 May 2002, at Potters Bar in England, a passenger train derailed leading to the death of seven passengers and injuries in a further 76. The derailment took place while the train was travelling over a switch at a speed of approximately 160 km/hour. As a consequence of the derailment, a part of the train ended up on a nearby platform. The investigation[47] revealed that derailment was caused by a switch blade that worked loose, as a result of a poor technical condition (loose connections, fatigue fracture, et cetera). These defects were in part the result of ongoing hitting of the open switch blade. In respect of the underlying factors, the investigation revealed that the maintenance

46 See: Train Derailment at Hatfield: A Final Report by the Independent Investigation Board, July 2006.
47 See: Train Derailment at Potters Bar 10 may 2002, A Progress Report by the HSE Investigation Board, May 2003.

personnel were poorly aware of the operation of specific parts of the switch, and that the importance of those parts was insufficiently acknowledged. Above all shortcomings in the documentation and lack of training played an important role. Following the accident, it also emerged that other switches in the region in question were in poor condition. Partly as a result of the findings, the infrastructure manager Network Rail retook control of the maintenance of the railway infrastructure, which before then had been outsourced to a subcontractor.

Grayrigg – England (2007)
On 23 February 2007, a passenger train derailed at Grayrigg, resulting in numerous personal injuries and one death. The derailment took place while the train was travelling over a switch at a speed of approximately 155 km/hour. The switch in question (just like switch 3B in Hilversum) was a crossover switch that was passed almost exclusively in a straight direction.

The investigation[48] revealed that the direct cause of the derailment was the presence of a loose switch blade. The switch blade had worked loose due to a fatigue fracture in a connecting rod, and several loose mounting parts. It emerged that these defects were to a considerable degree the result of the fact that the switch blade had been repeatedly hit while in open position, by the inside of passing train wheels. The hitting of the switch blade and the defects had not been observed prior to the accident.

In the framework of the investigation into the derailment in Grayrigg, tests and calculations were carried out into the possible consequences of hitting open switch blades. These for example revealed that flange-back contact, at least with this particular type of switch, could lead to forces in the operating system of the blade which are a factor of five higher than those without flange-back contact. In response, on the basis of calculations, it was concluded that the technical service life of certain parts of the operating system could be massively reduced. The reduction could be of the order of magnitude from 'dozens of years' to 'a few weeks'.

Following the accident, it became clear that a large proportion of the switches was in such a condition that flange-back contacts could occur. Besides that, the method used for determining the free wheel clearance was identified as incorrect. For the English railway infrastructure manager (Network Rail) at the time, this outcome led not only to a modification of the design of the connecting rods in question, but also to the strengthening of the relevant maintenance instructions. The alterations to the instructions related among others to the inspection of the free wheel clearance, and to the actions to be undertaken in the case of evidence of flange-back contact.

Bretigny-sur-Orge - France (2013)
On 12 July 2013, at Bretigny-sur-Orge in France, a passenger train derailed resulting in the death of seven passengers and injuries to 32. The derailment took place while the train was travelling at a speed of approximately 135 km/hour over a switch. As a consequence of the derailment, a part of the train ended up on an adjacent platform.

48 See: Derailment at Grayrigg 23 February 2007, Report 20/2008/V5, July 2011.

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The investigation[49] (which at this moment is still not concluded) revealed that the derailment was caused by welded plates, with which the switch blade was attached to the frog, working loose. This in turn was brought about by a crack in the frog, which had started several months previously. In respect of the underlying factors, the investigation revealed that in particular the frequency and the method/execution of switch inspections (which as far as can be determined at present were carried out in accordance with the regulations) played a role.

49 See: Rapport d'étape sur le déraillement du train Intercités no 3657 le 12 juillet 2013 à Brétigny-sur-Orge (91), Bureau d'enquêtes sur les accidents the transport terrestre, janvier 2014.

APPENDIX F

OTHER INVESTIGATIONS INTO THE HILVERSUM DERAILMENT

OTHER INVESTIGATIONS INTO THE HILVERSUM DERAILMENT

F.1 Introduction

In addition to the investigation by the Dutch Safety Board, the derailment at Hilversum was also investigated by the railway infrastructure manager (ProRail), the supplier of the point machine (Bombardier) and the train operator (NS Reizigers), and the Human Environment and Transport Inspectorate (Inspectie Leefomgeving and Transport - ILT). The summaries of these investigations, with respect to the area of focus and most important conclusions, are given below.

F.2 ProRail investigation

In respect of the derailment in Hilversum, ProRail investigated the necessity for acute safety measures, the technical condition of switch 3B in Hilversum and the facts and causes of the derailment.

Acute safety measures
In response to the derailment, ProRail established a special safety team to determine the extent to which acute safety measures were needed in order to guarantee the safe passage of switches like switch 3B. On the basis of the available information concerning the facts and causes of the derailment, the team reached the conclusion that the derailment was probably caused by the failure of the ring of the right-hand switch blade of switch 3B as a consequence of a fatigue fracture caused by repeated flange-back contacts. On that basis, a so-called safety report was sent, with the instruction to replace the ring in all switches operated by a single-point EBI switch, where flange-back contacts occurred (or to clamp the switch or to exchange the locking rod with the detection rod[50]). The safety report was subsequently further supplemented in the sense that the instruction also applied to switches with multipoint operation, and switches on which the blades had recently been replaced.

Technical condition of switch 3B in Hilversum
ProRail investigated the technical condition of switch 3B.[51] Once the switch 'as a whole' (including sleepers) had been transported to a sealed site, the following measurements

50 The detection rod is not equipped with a release mechanism and ring.
51 The findings are summarised in the 'Report on the technical condition of points 3B', 12 March 2014.

were carried out: the angle of incline in the rail head, the track gauge and its narrowing or widening, the free wheel clearance and the (horizontal/vertical) wear on the rails, the contact marks on the right-hand switch blade and the functioning of the EBI switch point machine. The conclusions of ProRail amount to the following:

- Several important components (including the blade supports and the slide chairs) demonstrated wear or were incorrectly dimensioned. The lubricant-free construction (Ekos-V rollers) was worn too far to be able to operate correctly. A number of the fasteners were also loose. The radius of the right-hand switch blade was too small at a crucial location.
- As a consequence of the non-conformities described above, in combination with the dirt present in the point machine, over the course of time, the free wheel clearance had become so large that the standard was exceeded. The measured values ranged from between 1389 to 1424 mm (while the threshold value is 1390 mm and the safety value 1398 mm).
- Because the free wheel clearance had become too large, the wheels of passing trains made contact with the locking side of the right-hand switch blade, as a consequence of which the release mechanism broke (due to fatigue).

Facts and causes of the derailment
ProRail investigated the facts and causes of the derailment.[52] The findings amount to the following:

- The immediate cause of the derailment was that the right-hand switch blade of switch 3B unintentionally shifted to the locked position. This was possible because the ring in the EBI switch point machine broke due to fatigue. This fatigue fracture in the ring arose due to the fact that the right-hand switch blade in open position was frequently hit, over a long period of time. The fracture was initiated in a residual machining burr. The right-hand switch blade was hit because the free wheel clearance had become too large. This clearance had become too large since the Ekos-V rollers were as a result of wear no longer functional, and since both the radius of the blade and the stroke of the EBI switch were too narrow.
- The fatigue in the ring was not noticed during inspection/maintenance. A reason for this oversight is that sole visual inspection is not sufficient to notice fatigue effects. In addition, it is possible that not all service engineers were conversant with the new type of ring (with two break links). The Ekos-V rollers were more worn than had been assumed on the basis of the maintenance regime. The maintenance and inspection regime, which is based on periodic inspection, takes insufficient account of the actual load and occurring wear.
- The maintenance on switch 3B was carried out up to 1-7-2013 by Strukton Rail on the basis of an OPC contract, between 1-7-2013 and 1-9-2013 by Asset Rail on the basis of an interim contract, and from 1-9-2013 onwards by Asset Rail on the basis of a PGO contract. The handover from Strukton Rail to Asset Rail was insufficient. Shortcomings observed by Strukton Rail were not explicitly reported to Asset Rail, and there is no evidence of whether inspections (by video and by walking) were carried out during

52 The findings are summarised in report P891470. The consulted version was version 1.5 (dated 14-10-2014).

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the transfer period. It is unclear to what extent Asset Rail undertook the inspections (as specified in the FMECA) in the months prior to the derailment. The non-conformities observed following the derailment (some of which had previously already been determined by Strukton Rail) were not determined by Asset Rail, and did not result in management measures that could have prevented the derailment.

Due to the hitting of the right-hand switch blade, the maintenance condition of various components was worse than assumed on the basis of the maintenance regime. The Ekos-V rollers were no longer functioning, the slide chairs should already have been replaced, and the loose clamp retainers should have been tightened. The maintenance and inspection regime is based on periodic inspections, the intervals of which are insufficiently harmonised to the technical condition and the actual load and occurring wear.

On the basis of the investigation, the investigation team of ProRail issued the following recommendations to the management of ProRail:

1. Fit the EBI switch point machines with a second line of defence (to prevent a single point of failure). Furthermore investigate which switch types are/are not suitable for single-point operation and/or for operation by point machines of the type EBI switch. In this respect, have an independent party draw up a safety case study.
2. Make policy choices in respect of the application of, for example, high or low blade profiles, the number of operating points at the various switch ratios and the type of point machine.
3. Audit the process of building/acceptance/application of switch constructions.
4. Make during the introduction or modification of safety-critical systems/components, standard use of an Independent Safety Assessor (ISA).
5. Have the FMECAs (drawn up by the contractors) approved by own specialists. Furthermore, on the basis of the maintenance plan of the contractor, draw up an assessment plan and on that basis inspect the work of the contractor.
6. Stop using Ekos-V rollers and investigate whether/how the existing Ekos-V rollers should be phased out.
7. Ensure that when modifying infrastructure components, the maintenance documents and the training for maintenance staff are also updated. Ensure that the revised maintenance documents are contracted on time.
8. Investigate which documentation is most suitable for facilitating the maintenance engineers, and provide that documentation.
9. Test proactively and risk-based whether the contractors have correctly undertaken their inspection and maintenance work. Have the test process audited.
10. When switching to another maintenance contractor, lay down requirements for the transfer of the information by the departing contractor, and proactively supervise the transfer.
11. Have an independent external party investigate the extent to which the tightening up of the Standard Framework for Safe Working Practice (Normenkader Veilig Werken - NVW) may have (had) negative consequences for the safe use of the railway network, due to the limited possibility for inspection and maintenance work on the railway. If this investigation reveals grounds, take improvement measures.

Fatigue testing and force measurements
ProRail had a number of fatigue tests carried out on the rings, both of the type used in switch 3B and a modified version. These tests, among other things, revealed that with the unmodified rings, with a switch load ranging from 1 to 11 kN, no signs of fatigue occurred after half a million load changes. On rings of which the surface had been grit-blasted, subject to a load ranging from 0 to 8.5 or 10 kN, fatigue fractures already occurred after approximately 85,000 and 40,000 load changes.

ProRail had load measurements carried out on a switch on which the open blade was hit. The tested system was a 1:15 switch with single-point operation, the flange-back clearance of which was approximately 17 mm. The measurements revealed that the mechanical load on the locking rods rose considerably due to flange-back contact, in terms of both the value of the tensile forces and the number of load changes.

F.3 Bombardier investigation

In response to the derailment, Bombardier established a working group (headed by an external expert) to investigate the cause, and to issue recommendations for improving the design and manufacture of the rings. The working group also assessed all other drawings and service/inspection instructions for the EBI switch.

The conclusions[53] from Bombardier amount to the following:

- The train derailed because the release mechanism of the locking rod of the right-hand switch blade failed as a consequence of a fatigue fracture in the ring.
- The fatigue fracture, which had started at the position of a residual machining burr, was due to ongoing hitting of the right-hand switch blade.
- The primary cause consisted of insufficient maintenance on the switch (as a consequence of which flange-back contact continued over a long period of time).

On the basis of the investigation, Bombardier considers the following measures necessary:

- *Short-term measures:*

  1. On switches that are correctly adjusted and well-maintained, no additional measures are necessary.
  2. Switches with an insufficient flange-back clearance and/or worn Ekos-V rollers must be adjusted and/or all necessary maintenance undertaken.
  3. At switches with flange-back contact, the rings must be replaced.

53 Derived from Product Safety Bulletin SI-100003 (open stage 4 or 5, final modification under development).

- *Long-term measures:*

    1. ProRail must ensure sound maintenance of the switches.
    2. Bombardier will adapt the production process for the rings in the sense that deburring will be carried out mechanically (rather than manually) and the final quality inspection will be increased from 10% to 100%. Bombardier will also consider submitting the rings to a surface treatment (grit-blasting or shot peening).
    3. During the next overhaul of the EBI switch point machines in use, the rings must be replaced.
    4. All safety-critical components of the EBI switch must be further assessed in respect of the risk of fatigue.
    5. An additional risk analysis (FMECA) must be carried out in respect of the 'second line of defence' with which ProRail wishes to equip the EBI switch point machines.

F.4 NS Reizigers investigation

In response to the derailment at Hilversum, NS Reizigers also carried out an investigation. At least in respect of the cause of the derailment, this investigation considered the technical condition of three bogies on the train in question, to assess to what extent this condition could have played a role in the occurrence of the derailment. (Viewed from the direction of travel), the bogies in question were the third, fourth and fifth on the front train set (4053). The investigation[54] that was carried out by NedTrain, included the following measurements and inspections: inspections of the in-built bogies, inspection/ measurements on the dismantled bogies (with in-built wheel sets) and inspection/ measurement on the dismantled wheel sets. Furthermore, the machining data from the most recent profiling/overhaul of the wheels were checked. A large number of geometric values for the wheel sets were also measured.[55] The findings were that the investigated bogies did demonstrate some damage/non-conformities, but that without exception these could be earmarked as being 'due to the derailment'. On that basis, NedTrain concluded that the investigated bogies and wheel sets complied with the requirements (applicable in the Netherlands) in respect of all inspected aspects.

F.5 Joint investigation by NS Reizigers and ProRail

NS Reizigers and ProRail carried out a joint investigation into the strategic-technical aspects of the derailment. The investigation, based on the Tripod philosophy,[56] was intended to allow the formulation of organisational improvement measures.

54 The investigation and findings are described in report NT/FS/MS/20140522/001-01 from NedTrain.
55 In respect of the wheel sets, the following were assessed: the thickness and height of the flange, the Qr size, the inside gauge, the tyre thickness, the rim diameter and the rim diameter difference, the hollow wear of the running surface, any over-projection and the tyre width. Measurements were also carried out to determine the extent to which the wheel sets demonstrated any run-out (in the middle of the axle, at the axle journals and at the inside of the wheel), axial play or radial out-of-trueness.
56 According to the report in question (ProRail-promise 402221) the Tripod Beta theory means that incidents/ accidents – with the exception of uncontrollable external factors such as meteorites, war, et cetera. – are the consequence of organisational/system factors (weaving flaws) that are deeply anchored in the organisation.

On the basis of the investigation – in concise form – the following conclusions were drawn, among others:

- ProRail and NS Reizigers attempt to comply with the external and internal regulations, but in practice, this was insufficiently inspected or ascertained.
- Risk analyses were undertaken by both companies in respect of derailments, but these were incomplete in respect of the possible scenarios. The cooperation between both companies in analysing the risks could be improved, in particular in relation to the interface between the two company's processes.
- As changes to the railway infrastructure concerns, in its communication, ProRail mainly restricts itself to the actual decisions; the substantive technical underpinning and/or risk considerations are not mentioned. The safety teams from ProRail do not work together with other interested parties or stakeholders. Within NS Reizigers, there is no system for ensuring that decisions by the Operational Control Centre Rail (Operationeel Controle Centrum Rail - OCCR) or National Policy Team Incident Management (Landelijk Beleidsteam Incidentmanagement - LBI) are communicated in good time to the Service and Support department for further follow-up.

F.6 ILT investigation

In its investigation, the ILT focused primarily on answering the question how the train derailment occurred and whether in that connection ProRail committed any violations of the Railways Act. The approach selected by the ILT was to follow the investigation undertaken by ProRail and to closely monitor the progress and follow-up of that investigation. The ILT arrived at the following findings:

- The design was inadequate (meaning that with the absence of a safety net there is a single point of failure).
- The finishing of the ring during manufacturing was insufficient.
- The point machine was not used in accordance with the design.
- The maintenance plan was insufficiently geared to the purpose.
- The maintenance undertaken deviated from the plan.
- The maintenance also demonstrated shortcomings already previously observed by the Inspectorate.

The ILT concludes that an inadequate design and defective production in combination with the poor maintenance condition led to the derailment. The ILT is of the opinion that ProRail carried out a sound investigation, but that the learning points need to be tackled more broadly. ProRail should not only solve the observed shortcomings in the specific objects or systems of this particular case, but should also use the findings from its own investigation to improve other processes and procedures. This for example means that ProRail must rapidly trace and eliminate all single points of failure (possibly still unidentified) in the railway network.

Furthermore, in these findings, the ILT once again sees confirmation of the outcome of the PGO study that was carried out in 2013. One important similarity relates to the

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observation that ProRail deviates from its own maintenance standards without managing the risks sufficiently. Against that background, it is essential that ProRail urgently implements improvement measures, in order to improve the management of safe network usability. The ILT will monitor the progress of those improvement measures. An abbreviated report of the results has been prepared.

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APPENDIX G

REFERENCE FRAMEWORK

The Dutch Safety Board has examined the findings from the investigation into the train derailment in Hilversum according to a reference framework. On the one hand this reference framework comprises the legislation and regulations, standards and directives. Wherever necessary, these are named in the main report. Furthermore, the reference framework for this investigation consists of three additional elements, as described in this appendix: i) fulfilment of the role of contract-awarding party, ii) safety management and learning from incidents and accidents and iii) cooperation in the chain.

G.1 The role of contract-awarding party

Parties in the railway sector who act as contract-awarding party take decisions on issues critical to the safety chain within the railway infrastructure. These include frameworks for laying down the management plan and key performance requirements, purchasing parts for the railway infrastructure, setting performance requirements for the network or maintenance work to be undertaken, contracting, carrying out risk analyses and identifying safety-critical elements. Decisions on these and other safety-related subjects clearly influence safe rail travel.

The Minister of Infrastructure and the Environment is the contract-awarding party for the management of the railway infrastructure, by granting a concession. This concession is granted on the basis of the Railways Act. The current concession (2005-2015) is awarded to ProRail. In this concession, requirements are laid down, the purpose of which is to guarantee that the railway manager analyses the safety risks, and sufficiently manages those risks with suitable measures. The concession also includes a duty of care to ensure that the main railway network can be travelled safely and efficiently. The Long Term Railway Agenda also lays down railway-related tasks that will be translated and specified in the management concession 2015-2025.

ProRail itself outsources maintenance of the railway infrastructure to contractors. The company operates two types of contract: A) output process contracts (OPC) in which ProRail specifies the maintenance work to be carried out and B) performance-based maintenance contracts (PGO) which describe the quality requirements the infrastructure must fulfil in terms of availability, reliability, sustainability and safety. In the PGO contract, the contractor has a certain degree of freedom in determining the tasks necessary for achieving these quality levels.

In purchasing new objects for the railway infrastructure, such as point machines, ProRail provides specifications to the supplier. These specifications include general requirements, external requirements (such as air pressure, temperature, electrical installations and conditions in and around the track), product characteristics (such as applicability, service life, safety of the system) and specifications governing maintenance and service.

There is a clear link between functional requirements and safety. The Dutch Safety Board believes that on that basis the contract-awarding party is responsible for the consequences of the functional requirements it imposes, and hence also for safety. The same applies to specifications drawn up for the purchase of new objects for the railway infrastructure. Furthermore, railway-related tasks as laid down in the Long Term Railway Agenda and translated in the new management concession to ProRail will continue to affect the policy of the parties involved, in the future. In that sense, these tasks could influence railway safety.

The Dutch Safety Board expects contract-awarding parties to draw up frameworks for managing the risks as far as reasonably possible. The Dutch Safety Board also expects contract-awarding parties and their contractors to call one another to account whenever it emerges that the execution of an order or contract, or the use of a particular type of product (whether or not in combination with other factors) engenders safety risks. After all, the responsibility for safety goes further than simply complying with legislation and regulations; it also requires all parties involved to deliver the best possible effort in promoting safety. The Dutch Safety Board therefore notes that the contract-awarding role also involves a supervisory function in monitoring the execution of the orders issued, according to the frameworks drawn up in that respect. This is a principle that can be considered as generally applicable.

G.2 Safety management and learning from incidents and accidents

Safety management
The Railways Act states that within the frameworks laid down, the railway companies are responsible for the safety of day-to-day operation. The Railways Act demands that railway companies lay down the measures they take to sufficiently manage their safety risks, in their safety management system (SMS).

The Minister of Infrastructure and the Environment, in her enforcement task, has an important role to play in further increasing railway safety. The Minister can call railway parties to account if they fail to take the (necessary) measures to manage risks. This is possible at the stage of approving the SMS, or in enforcing the means that according to the SMS should be provided.

The railway companies must individually as well as jointly ensure sufficient management of safety risks by taking suitable measures. In the Third Framework Document on Railway Safety, a safety vision is described, which consists of the following four elements:

- Striving for permanent improvement: a process of permanent reduction of the risk of fatalities, injuries and damage. Even if the relevant targets are achieved, the principle continues to apply that measures with a positive effect on safety must certainly not be neglected if they are desirable, achievable and affordable ('from good to better'). In the framework document in which government policy is laid down, the ALARP principle[57] is identified as the yardstick for sufficient management of safety risks.
- Clearly identifying the available political-social choices when it comes to safety.
- Acknowledging and accepting risks: as well as taking preventive measures, it is equally important to acknowledge the effects and consequences of incidents, and to manage those effects.
- Operating safety management as an essential precondition for achieving permanent improvement, and enabling the structural and preventive management of safety issues. The striving for permanent improvement must take place in such a manner that safety is part of an integrated approach that also takes account of cost effectiveness.

Learning
The Dutch Safety Board expects the manager of the railway infrastructure, and the contractors and manufacturers of products for the railway infrastructure to learn lessons from previous incidents (both at home and abroad) and to make use of the knowledge of risks to increase the safety, or improve the product. In the judgement of the Board, it is thereby essential that the parties uphold a broad perspective on learning. On the one hand, the parties must be actively involved in solving the direct problem, for example by taking corrective measures. In this way, the direct causes of the unsafe situation will be eradicated and the negative consequences limited, as far as possible. On the other hand, the parties should grasp any incident or accident to study the underlying factors of a more structural nature. These for example include the internal organisation, the procedures, the interface with other parties and the underlying ideas, understanding and frameworks. In this way, structural underlying causes of unsafe situations can be acknowledged and avoided.

G.3 Chain cooperation

Railway companies can always suddenly face unexpected risks; after all, not all risks are predicable. For that reason, it is vital that all parties in the railway sector attempt to jointly identify and acknowledge new risks in good time, so that they are able to take the necessary (safety) management measures. In that connection it is important that organisations remain in touch with one another, share information, and remain aware of one another's tasks, responsibilities, authorities and abilities. To ensure the safety of the railway, all parts of the chain must be viewed as a coherent whole. In the case of the derailment in Hilversum, the chain in question starts with the design, the production and

57 ALARP = as low as reasonably practicable. Responsible parties must therefore ensure that they take all available measures, unless a measure involves demonstrably unreasonable costs and/or consequences.

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purchase of point machines right through to the installation, use and maintenance of the switch as a whole. Each of these elements can influence the safety of the railways and more specifically the safe use of a switch.

Whenever a chain functions correctly from the point of view of safety, the chain demonstrably contributes to solving or preventing unsafe situations on the railway.

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