RAAD VOOR DE TRANSPORT VEILIGHEID

PASSENGER TRAIN DERAILMENT

at Baarn

20 August 1999

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FOREWORD

Derailments are not included amongst the traditional safety bottlenecks in rail transport. That much is clear. The safety bottlenecks are based on actual accidents which have occurred with some regularity. It goes almost without saying that spontaneous derailments occur extremely rarely. In the laying out and construction of the rail infrastructure in our country, no account was taken of trains derailing. The assumption is that trains will not spontaneously leave the rails. When such an occurrence does take place, as in Baarn on 20 August 1999, there is every reason to thoroughly analyse the derailment. The sole purpose of this analysis is to contribute towards preventing a repetition. The Council decided to investigate this derailment, focusing in its study on the “manageable factors”, according to the TRIPOD method. This method was developed by the universities of Manchester and Leiden, on behalf of a major petrochemical company. The analysis method above all attempts to identify those factors which can increase safety, and which can be influenced by the management and/or managers of the organisations in question.

During the initial investigation, there was much discussion between the Council and the employees of the companies involved in the accident. Because this derailment was primarily hallmarked by technical aspects, above all the maintenance and overhaul workshops of NedTrain were the subject of study. From the very beginning, the Council received full cooperation from these workshops, although, given the character of the investigation, this was not always easy for the company involved. The Council would particularly like to express its appreciation for the employees and management of the workshops of NedTrain, who showed such excellent cooperation during this study.

The Management of Netherlands Railways have informed the Council, by letter, that suitable measures have now been taken to prevent a recurrence. Naturally, the measures taken after the investigation are not included.

The Hague, 31 August 2000

Chairman of the Council
Pieter van Vollenhoven

Secretary Director of the Council
S.B. Boelens

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SUMMARY

On 20 August 1999, a passenger train type Materieel 64, derailed in Baarn. This train had just left the station at Baarn, heading towards Utrecht, crossing the main Amsterdam-Amersfoort tracks. The train derailed at the last set of points where the single track towards Utrecht branches off from the main Amsterdam-Amersfoort tracks. The speed at the moment of derailment was relatively low, approximately 40 km per hour. As a result, the consequences were fairly minor.

When constructing the Dutch railway network, it was assumed that trains would not derail spontaneously. Trains pass obstacles located close to the rails, at speeds of 140 km per hour. As a result, derailments could have very serious consequences. The accident in Eschede in Germany demonstrates this fact. The cause of the derailment in Baarn was the failure of a wheel, due to fatigue cracks. Materieel 64 has been in existence for more than 30 years. The average service life of rolling stock is approximately 30 years. For this reason, additional emphasis on this phenomenon would seem obvious. Fatigue cracks in construction are as such not unavoidable and permissible. However, at least two conditions must then be met. It must be possible to guarantee the tracing of the cracks, and the speed with which the crack is expanding must be precisely known. The standard means of monitoring these factors consists of inspections and monitoring the number of changes in load. For wheels, a rough guide to the latter monitoring is the number of kilometres travelled.

As a carrier, NS Passengers is fully responsible for the stock deployed in passenger transport. NS Passengers does not itself carry out the maintenance on rolling stock. This maintenance is subcontracted to NedTrain. This company, which is part of the NS Holding company, is a maintenance company certified by Railned, on behalf of the government.

The investigation carried out demonstrated that the method used for tracing cracks is not truly reliable. In addition, until the derailment in Baarn, the rule applied that a wheel had to be investigated for cracking, once every two years. In fact, this rule was not complied with. The speed with which cracks

developed in the wheels was not known, and no research was carried out into this subject. The scope of the changing loads was also not monitored. As a result, the safe running of the wheel sets could not be guaranteed, and a train was derailed, in Baarn. The conclusion which must be drawn is that the workshops carrying out these investigations were incorrectly unreservedly certified by Railned.

On the basis of these findings, the Council issues the following recommendations.

The Management of NS Passengers is recommended, in the shortest possible time, to guarantee the safe running of Materieel 64, by:
- increasing the reliability of the rapid tracing of fatigue cracks in inner wheels;
- idetermining the speed with which cracks develop;
- icomplying with the periods laid down for crack investigations.

If NS Passengers fails to guarantee safe running, according to these measures, it is recommended that at least all inner wheels on type 275 bogies be replaced.

The Management of NS Passengers is recommended to develop a maintenance strategy for all passenger stock, guaranteeing the safe running of this stock, at all times.

The Minister of Transport, Public Works and Water Management and Railned are recommended to reconsider the policy instrument of compulsory certification of maintenance companies in combination with the standard M-004, which calls for assessment of all business processes.

CONTENTS:

1. INTRODUCTION

On 3 June 1998, in Eschede, Germany, the ICE Munich-Hamburg derailed at a speed of 200 kilometres per hour. The ICE derailed because one wheel in one wheel set failed. As a result, the third carriage of the train collided with the pillars of a viaduct which collapsed, following the impact. The fourth and following carriages then crashed into the collapsed bridge. The accident led to the loss of approximately 100 human lives and numerous injuries. The direct cause was the mechanical failure of a wheel.

The train is viewed as a safe means of transport. This safety is based on two solid foundations. The first is travel subject to signals. A train only starts moving, once it has been determined that the route to be followed is free of other rail traffic. The second foundation, effectively the subject of this investigation, is the demonstrated reliability of the technology used ‘on the rails’. Transport by rail is more than 150 years old. Empirical knowledge in respect of techniques and materials employed is therefore considerable.

On the basis of this extensive experience, a number of points of departure may be assumed. One of these is that a train will not derail, for no reason. Trust in the guidance of wheel sets (the combination of an axle with two wheels) by the rails is so great, that trains are permitted to travel at high speed through stations and alongside the pillars supporting viaducts. Throughout the country, intercity trains travel at 140 kilometres per hour along platforms, situated close to the track. Whilst travelling, the correct functioning of the wheel sets (four for each carriage, each weighing almost a thousand kg) is not monitored. It is simply assumed that this system is so reliable, that monitoring during travel is not necessary.

Nonetheless, a passenger train did derail in Baarn, due to the technical failure of a wheel. At that moment, the train was crossing the main Amsterdam-Amersfoort line, and continued travelling, derailed, over a single-track section. The speed at which the train was travelling was relatively low, approximately 40 kilometres per hour, and there were no obstacles. As a result, there were no injuries and damage was limited. The precise moment at which a wheel fails can of course not be predicted. Such an event could occur anywhere. In Eschede, where a high speed train derailed at a speed which cannot yet be achieved in the Netherlands, everything which could go wrong, went wrong. In Baarn, the opposite was the case. Nonetheless, the derailment in Baarn was a serious accident, given the assumption that such an accident cannot take place. For this reason, the Council decided to investigate this accident, in order to determine how it occurred, and how recurrence can be prevented.

2. NS PASSENGERS

NS Passengers, one of the core companies of the NS Group, carries almost one million passengers every day. In providing this transport performance, almost 11,000 staff are employed. In 1998, the company generated turnover of 2,666 million guilders. To carry these passengers, some 2700 carriages are available, the majority (approximately 1700) forming part of electrical train sets, with their own traction. The remainder are drawn carriages, propelled by separate locomotives.

The stock used for carrying passengers has a long service life. In the rail business, a service life of 30 years is normal. The stock used by NS Passengers varies widely, in terms of year of construction. The interregional stock, the modern streamlined double-deckers, date from 1994. The classical, somewhat rectangular double-deckers have been running since 1987. The first “koploper” unit, with the high seating position for the driver dates from 1978. The classical stopping train stock, which for many years has been the face of NS, has been in use since 1964. This stock derives its name from this date: Materieel 64.

According to article 1 of the current Railways Act, NS Passengers bears overall responsibility for the safe carriage of passengers, and as owner, is fully responsible for the stock used for that purpose. This situation, however, has only been current for a few years. Prior to this time, the stock was owned and managed by the company component now known as NedTrain. NedTrain is an independent company within the NS Holding. Following the formal transfer of the passenger stock to NS Passengers, the implementation of maintenance came under the auspices of NedTrain.

3. THE LOCATION

The connection between Baarn and Utrecht is maintained by a stopping train, which travels backwards and forwards between the two places. The single-track section Den Dolder–Baarn joins the twin-track section of the Amsterdam–Amersfoort line, just before Baarn station. Baarn station itself has 4 tracks. The stopping train Utrecht-Baarn crosses over the Amsterdam–Amersfoort line, and stops on the track located immediately behind the Baarn station buildings. This track is adjacent to the two Amsterdam–Amersfoort tracks. For the stopping train, Baarn is starting point and terminus.
By placing the stopping train on the adjacent track, immediately behind the station

Fig. 1 The site of the accident

buildings, the main tracks are kept free for traffic on the Amsterdam–Amersfoort line. The placing of the track behind the station buildings means a short walk for the passengers. Following arrival in Baarn, it takes some time to prepare the train for travelling in the opposite direction. Following departure from Baarn, the stopping train once again crosses the main line. On 20 August 1999, one wheel of the stopping train derailed in the points where the Baarn–Utrecht line branches off from the main Amsterdam–Amersfoort line. The stopping train finally halted 900 metres after the point of derailment of the wheel, on the single-track section.

4. THE COURSE OF EVENTS

On Friday 20 August 1999, at 17.00 hours, the stopping train, a four-carriage train set of Materieel 64 arrived from Utrecht, in Baarn, at track 1. The driver switched off the entire set, and headed for the other cab, to return to Utrecht. Once in the cab, he switched everything back on, and as prescribed, carried out a minor brake test. Once all passengers had embarked, the driver closed the doors. This train had no conductor. The driver then departed towards Soestdijk. This route crosses the main Amsterdam–Amersfoort line, via four sets of points. The speed of the train was 35–40 kilometres per hour. A maximum speed of 40 kilometres applies for the points.

On passing the second set of points, the first – left-hand – wheel of the second motor bogie of the second carriage derailed. The wheel travelled over the end of the crossing of the set of points, and fell back into the correct track. When crossing the fourth and final set of points, the wheel became fully derailed. The passengers noted the bumping motion and guessed that the train had become derailed. Approximately 200 metres after the derailment, the driver felt that the train was no longer travelling correctly. His first thought was poor condition of the track section, and he continued at low speed. Approximately 700 meters from the set of points where the set of wheels had derailed, the train passed a level crossing with no barriers. Until this point, the first set of wheels had been travelling more or less parallel to the rails. As a result of the collision between the derailed set of wheels and the concrete foundation of the crossing, the set of wheels and hence also the bogie twisted further to the left, seen from the direction of travel. By this stage, the train had begun to shake. The driver no longer trusted the situation, also as a consequence of the unusual noises he could hear. He therefore stopped the train. At this moment, a passenger banged on the driver's cab door, calling that the train was derailed.
The passengers present on the train, of whom none were injured, did not want to wait in the train, for assistance, but wished to continue their journey, independently. The only option was to walk along the track. The driver requested the passengers not to walk towards Baarn, because the Amsterdam–Utrecht line was in use, carrying intercity trains travelling at 140 kilometres per hour. The passengers were advised to walk to Soestdijk. The traffic controller for the Gooi line had given permission for this action. Because there was no conductor on the train, and the driver wished to remain with the train, the passengers walked to Soestdijk station, unaccompanied. Subsequently, the duty shift of NS Passengers checked whether there were still passengers at the station. However, all had already departed. The identify of the passengers in question was never determined.

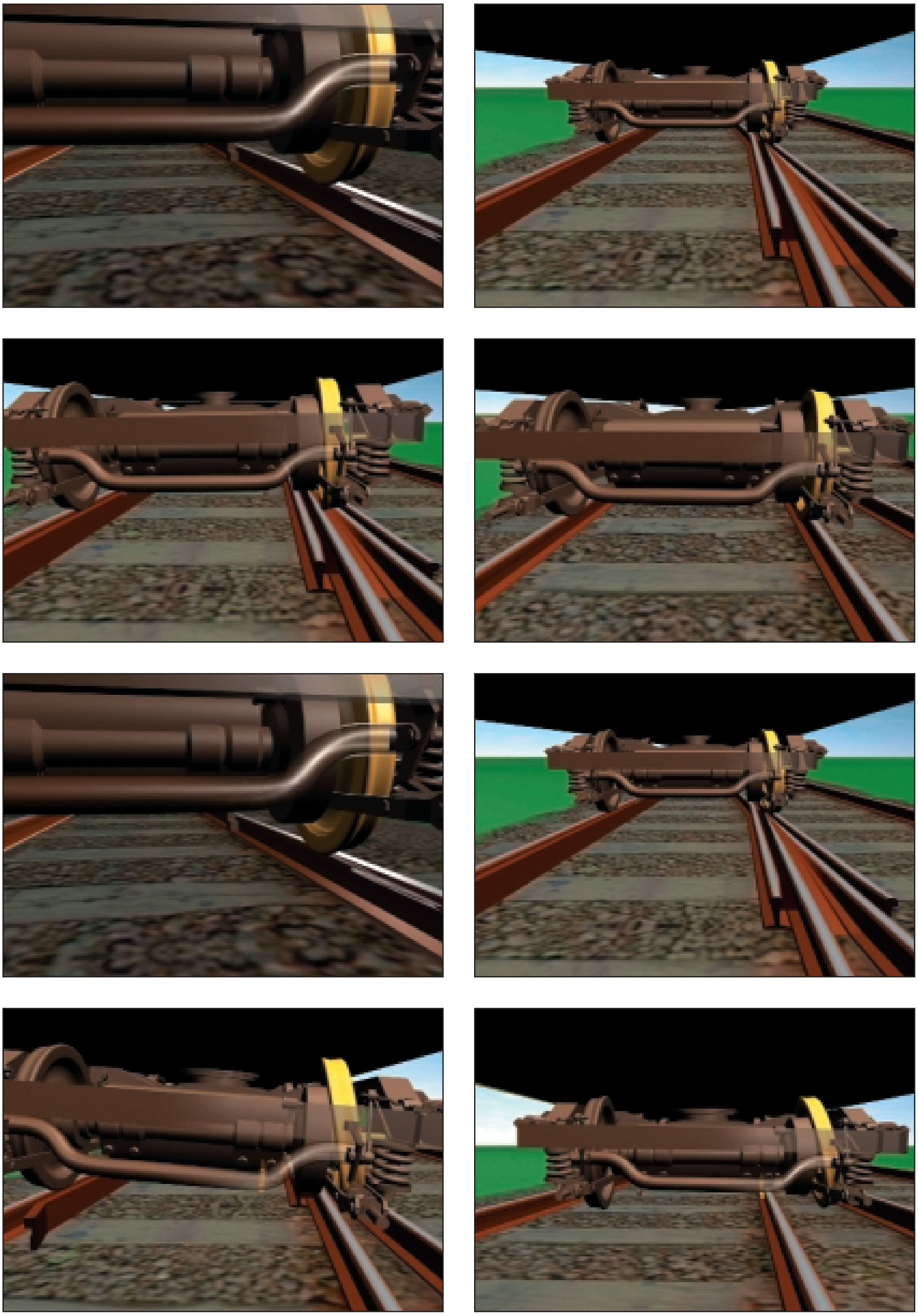

Fig. 2 The bogie first derailed in the second set of points on the main Amersfoort–Amsterdam line. After this set of points, the bogie returned to the rails. At the fourth set of points, the bogie derailed completely.

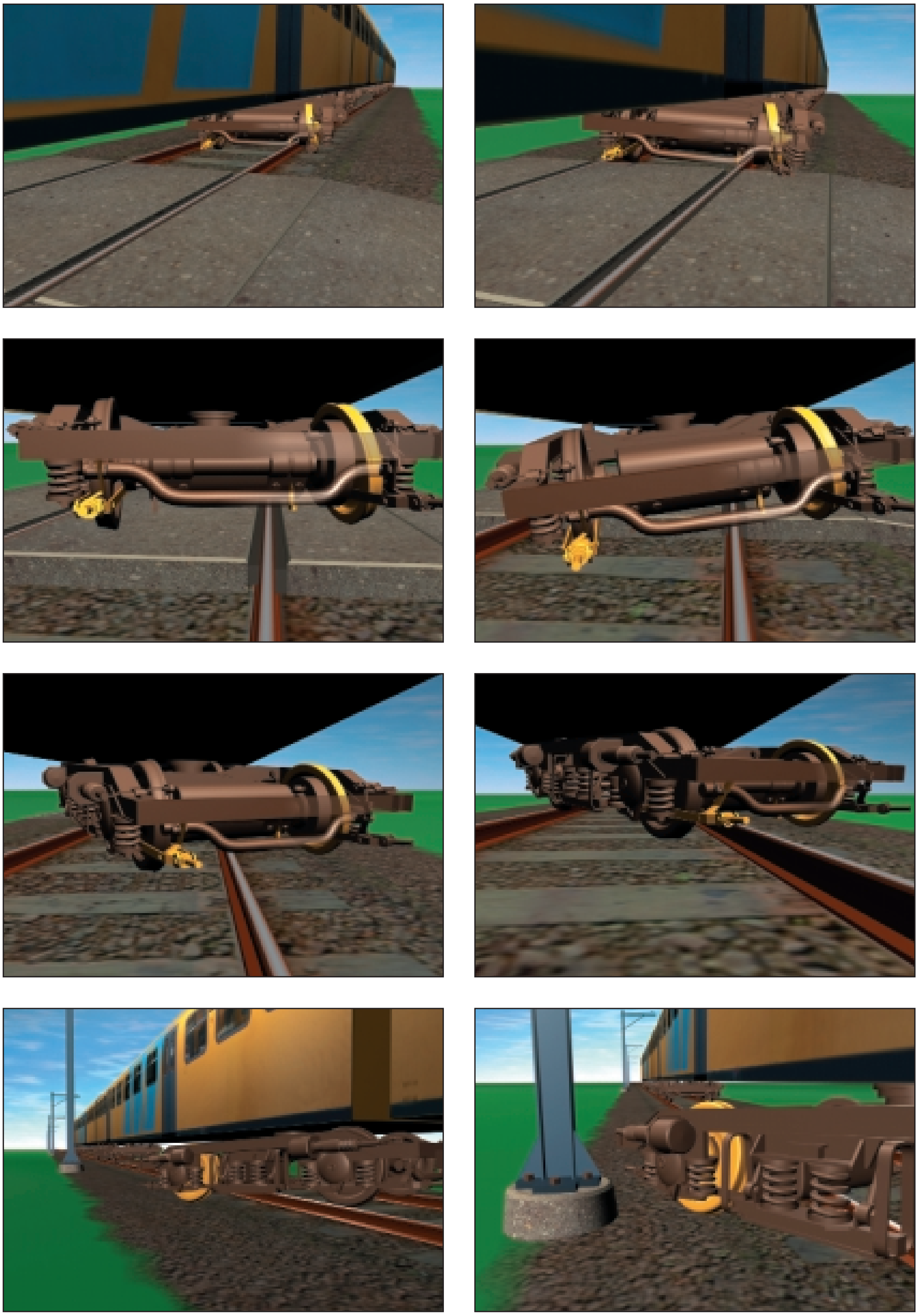

Fig. 3 The bogie collided with the foundations of a crossing, on the single-track section, turning fully out of line. The bogie then left the track clearance envelope.

5. MATERIEEL 64

5.1 Characteristics

The prototype of this motor train set, which consists of four carriages, was completed in 1961. In 1964 and 1965, 30 motor train sets of this type were built. Each carriage consists of a body and two bogies. A complete carriage weighs more than 40 tonnes, including the weight of the bogies. The weight of a bogie is above all dependent on the type: carrying bogie or motor bogie. In carrying bogies, the wheel sets are not driven. Carrying bogies weigh approximately 5.6 tonnes. For motor bogies, the wheel sets are driven. Here, the motor is suspended in the bogie. As a result of the weight of the motors, the motor bogies are much heavier. They weigh approximately 10.5 tonnes. With a four-carriage Materieel 64 set, the 4 bogies in the two centre carriages are motor bogies. The bogies beneath the first and last carriage (with cabs) are carrying bogies.

Fig. 4 Materieel 64. The oldest electrical passenger stock in use by NS Passengers.

Trains easily travel 175,000 kilometres a year. A train, built in 1964, has on average travelled 6 million kilometres.

5.2 Design

Materieel 64 has been in use for more than 35 years. This means that the design phase for this stock was concluded some 40 years ago. A very different era. Computers and calculators were not then used in design processes. All necessary calculations were made using pen and paper and the slide rule. Today, wheel sets are calculated using the ‘finite element method’. Using this computer-based calculation method, it is possible to make extremely accurate calculations for all possible construction elements, according to all imaginable load patterns. It is thus possible to accurately predict the behaviour and service life of all construction components such as bogie frame, wheel sets, axles, etc.

On the basis of these calculations, the manufacturer of the components can indicate a maintenance period and service life of a specific component, with considerable accuracy. The specifications from the manufacturer then in part form the basis for maintenance periods laid down by NS Passengers. Maintenance periods represent a crucial element in safety monitoring.

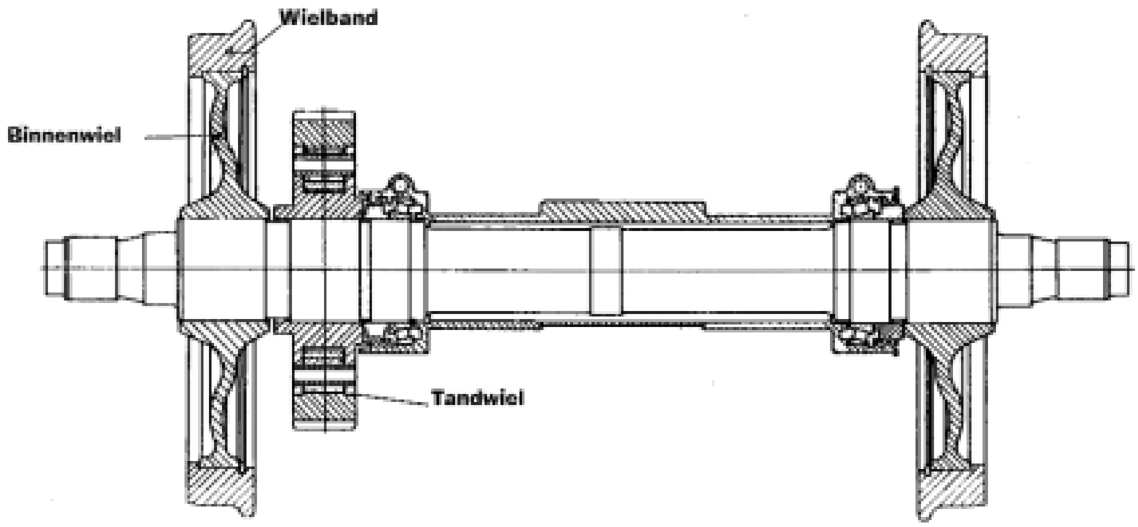

Fig. 5. Type 275 wheel set. The wheel set is part of a motor bogie. During re-profiling, the profile of the tyre is returned to its original shape. The tyre becomes thinner. In re-tyring, the worn-out tyre is replaced by a new tyre.

When Materieel 64 was designed, these refined methods were not available. The result was not a worse bogie system. In any responsible design process, uncertainty is translated into greater safety margins. For this reason, less technical specifications are available for old bogies than for modern bogies. As a consequence, NS Passengers does not have specifications from the manufacturer relating to service life, with which the wheel sets or bogies of Materieel 64 must comply. When no technical specifications are available, during maintenance, only the traditional working methods can be employed. The service life of components is hereby determined, in practice. Periodical technical inspections are then required to guarantee safety.

6. MAINTENANCE

6.1 System

The Service Regulations for Main and Local Railways, based on the current Railway Act of 1875, features two articles relating to maintenance. Article 55 deals with the preparation of rolling stock for daily operation. Once a day, carriages and locomotives must be inspected. This daily inspection, now carried out on behalf of NS Passengers by NedTrain, includes inspections of safety-critical systems and functional checks of systems essential for safety, for example brakes and also minor repairs. In a number of cases, instead of once a day, inspections can also be carried out once every 48 hours.

Article 46 of these Regulations states that rolling stock must be investigated according to a timetable for periodic maintenance, approved by the Management, and must be kept in a condition whereby it can at all times be safely run. The Management of NS Passengers elaborated this article, by drawing up a number of maintenance sheets.

In this framework, above all the A-sheets and the C-sheets are relevant. The A-sheet imposes a compulsory maximum maintenance period, for all stock types. The C-sheet determines the maximum maintenance periods for the short term. In work descriptions, prepared by the company carrying out the maintenance, a determination is then made as to precisely what should happen in a short-term maintenance inspection. In preparing these regulations, economic considerations are also made. The more accurately the behaviour of a specific component is known, the more these periods may be extended or shortened. The experience acquired with a component always forms an important source of information in this process.

The A-sheets break down into various headings. For maintenance, a carriage is divided into a number of components. For example, Materieel 64 is divided into the body (the yellow steel frame with fixed content such as wall covering and doors) and the main components, respectively. Materieel 64 features the following main components: carrying bogie/wheel set, motor bogie/wheel set, traction motor, motor compressor, motor generator and finally the battery. The characteristic of a main component is that it is identifiable. Every main component as it were has its own name. Everything carried out on the main component is recorded. The major advantage of this system is the mutual exchangeability of main components. The service life and therefore also the maintenance periods of main components diverge considerably. If a specific main component requires maintenance, or is due for replacement, the main component in question is removed and immediately replaced by another overhauled unit. The carriage can then be put straight back into service. The workshops have a stock of overhauled main components, immediately available for building in.

Main components themselves in turn consist of a number of components. A main component in this maintenance system has only one construction component. The construction component literally and figuratively bears the name of the main component, the name plate or preferably the identification number. This number is physically attached to the component. In addition, a main component consists of wear parts and exchange parts. Wear parts are economically and technically non-repairable; wear parts are therefore replaced by new units, as necessary. Exchange parts are repairable.

Exchange parts are repaired, functionally fully overhauled and reused. Unlike the case for main components, no separate administration relating to specific parts is maintained for wear parts and exchange parts.

A wheel itself is not a main component in the maintenance system of NS Passengers, but is a wear part, and as such is part of the main component ‘wheel set’. A motor wheel set is a shaft fitted with a gear for the drive system and two wheels. In compliance with sheet A, motor bogies of Materieel 64 are overhauled every 1.5 million kilometres travelled, or earlier if the tyre is ready for replacement. Because a wheel set travels approximately 175,000 kilometres per year, this means that a wheel set must be fully overhauled once every 8 years. In addition, every day, or once every 48 hours, the wheel set is inspected, and periodic maintenance is carried out according to the C-sheet (every 48 operating days or every 23,800 kilometres travelled). Here, a visual inspection is carried out, functions are tested, settings are checked and any necessary repairs made. Wear parts, with a shorter service life than 2 years, are replaced as necessary.

6.2 Fatigue cracks

If passenger stock were designed perfectly, no fatigue cracks would occur, which could represent a problem to safety. Rolling stock is normally manufactured in steel. This material does have a fatigue strength, but only if the load and fluctuations in load are above a certain limit. If the loads are below the fatigue threshold values, the material in principle has an infinite service life. Fatigue cracks will then not occur. In the nineteen sixties, this was also the guiding principle in designing railway stock. At universities, students were taught to design constructions in such a way that these cracks would not occur.

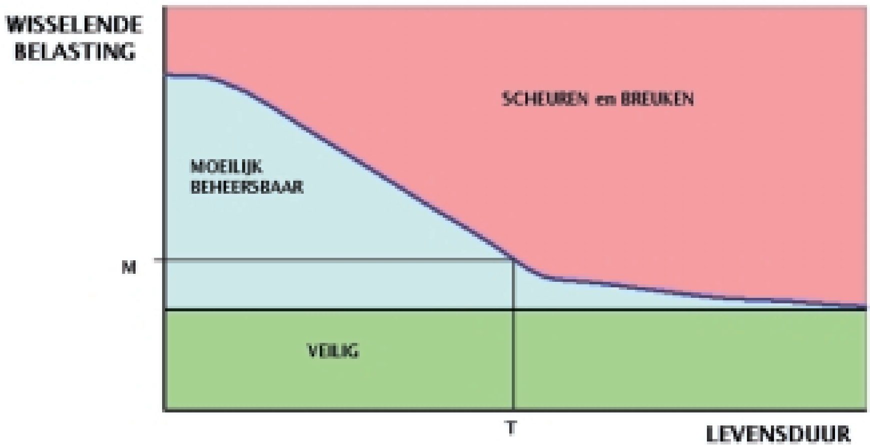

Fig. 6. The behaviour of steel under fluctuating loads. Below the fatigue threshold, the service life is infinite, i.e. this is the safe zone. Above these thresholds, the service life is limited. In the event of a fluctuating load equivalent to M, the expected service life is T years. On railway stock, this could in principle be more than 30 years.

If a fatigue crack is identified in a wheel or other component, the situation changes quite fundamentally in terms of service life, from one moment to the next. As long as no fatigue cracks have been observed in a construction component or wheel, it may still be assumed that the construction component has an infinite service life. The tensions in the construction are then in the green zone, shown in figure 6. The construction thus has an infinite service life. Once a fatigue crack has been observed, one thing is certain: the service life is limited. As such this is not a problem. Cracks are not by definition non-permissible.

Aircraft are built in aluminium. In the event of load fluctuations, aluminium always has a limited service life. For aluminium, the graph shown in figure 6 consists only of parts which are difficult to manage, and cracks and fractures. Unlike steel, therefore, aluminium does not have an unlimited service life if the loads remain within the threshold values imposed. (The safe zone in fig. 6). However, this is no hindrance to building in aluminium. The same also applies for steel. However, a number of limiting conditions must be complied with. It must be possible to trace cracks in time, and with absolute certainty. In addition, the cracking behaviour, with its most important parameter the speed with which the crack is developing, must be precisely known. Finally, the service life of the construction must be monitored. Fatigue cracks are brought about due to fluctuations in loads. The normal instrument for monitoring fatigue cracks is to record the number of fluctuations in loads. For wheels, this equates to determining the number of kilometres travelled.

Beyond maintenance laid down via maintenance periods, the maintenance system has no other safety net than the general visual inspection for externally-visible shortcomings, also carried out periodically. During such inspections, fatigue cracks are not easily located. Fatigue cracks are in fact only discovered if directly sought, using specific equipment. For example, the first fatigue crack in wheels in type 275 wheel sets was discovered during a non-regularly implemented inspection. There are no other possibilities for observing these cracks. The regulations for checking components for fatigue cracks and compliance therewith therefore determine the degree of certainty with which these cracks can be identified.

6.3 Flat points

Not everything is absolutely manageable and controllable. In railway traffic, flat points on the tyres are always an uncertain, difficult factor. Flat points generate considerable, highly fluctuating loads, which in turn have a major effect on the expected service life. Generally speaking, flat points arise due to a certain way of braking. Also during braking, a wheel must continue to rotate, because the braking force exercised on the train, with a rolling wheel, is always higher than with a blocked, sliding wheel. Given a simple brake system, full braking can result in the blocking of the wheel set. Due to the considerable force exercised by the brake blocks on the wheel set, the wheel set no longer rotates, and the wheel set becomes blocked. Because the train, carriage and bogie are not yet stationary, the no longer rotating wheel set slides over the track. Due to this sliding effect, a flat point occurs on the hard steel tyre. On modern passenger stock, an advanced anti-blocking system guarantees that the wheel sets do not block. As soon as this possibility is threatened, the braking force is reduced, so that the wheel once again rotates. This is not always successfully achieved, as a result of which even on modern passenger stock, flat points do arise on the tyres. Materieel 64 has an anti-blocking system, which is relatively simple. Flat points are therefore a constantly recurring phenomenon. Materieel 64 does have block brakes as opposed to modern disc brakes. Block brakes have the advantage that they act on the running surface of the wheel. As a consequence, on this stock, flat points can be worn away.

Flat points cannot always be avoided. Flat points clearly have negative consequences for the stock. A rotating wheel with a flat point as it were hovers above the rail, when the flat point passes over the top of the rail. The wheel then falls back onto the rail. Although this fall is only in the order of several tenths of millimetres, the impact force arising is far higher than the normal dynamic wheel load. As a result, the flat point becomes greater. It is also not excluded that impact loads arise, which are beyond the values assumed in the design.

Tackling flat points is a difficult problem. The only solution is to return the wheel to its round condition, for example using a ground wheel-lathe. In principle, this is a type of lathe using which, with a hardened steel cutter, the worn profile of the tyre is returned to its original shape, and the wheel is once again made perfectly round. The wheel sets need not be removed, but simply remain mounted on the train. Tracing flat points on wheels is also very difficult. The rejection dimension is half a millimetre. A visual inspection of the wheels in the line workshops during the short-term maintenance inspections, whereby the inspector is able to walk beneath the train, should identify such points. However, they are poorly visible, and not the entire circumference of the wheel can be checked. In other words, this inspection is not a watertight system. Otherwise, the system is dependent on conductors and drivers complaining about poor running, and the accompanying noise generated by the train. The initial background to the accident in Eschede in Germany was a tyre which was not completely round, but was slightly oval in shape. The out-of-roundness was some tenths of millimetres. The effect is comparable to that of flat points.

6.4 Certification

For safety purposes, maintenance is essential. For this reason, rules are also laid down in law and the regulations, which must guarantee a minimum maintenance system. In the still current 1875 Railways Act, this guarantee above all lies in the specific technical regulations. For a number of years, a new instrument has been added in this connection. Every company wishing to travel on the Dutch network must sign an agreement with the Minister. In this access agreement, it is laid down that maintenance of railway stock to be used on the Dutch network may only be carried out by companies approved by Railned. Companies are approved once the company processes have been examined, evaluated and approved by Railned. Such approval is not without cost.

7. ANALYSIS

7.1 Standards

For the safe operation of a train, wheel sets play a central role. In the railway world, this fact has been recognised. For this reason, the Union Internationale des Chemins de Fer (UIC), initially a voluntary cooperative venture between the former national railway companies, drew up standards for wheel sets. These standards, representing agreements between the members of the Union Internationale des Chemins de Fer, were raised several years ago, by Railned, on behalf of the Dutch government, into formal standards. These standards lay down a number of requirements, which are relevant with every delivery of wheels or wheel sets. These standards certainly do not form the full package of requirements imposed on a specific wheel on a specific train. For wheel sets, on the basis of the formal regulations, the following standards apply:

UIC leaflet	812-1	quality requirements for inner wheels
UIC leaflet	812-4	tyre fit and tolerances
UIC leaflet	812-5	tolerances and surface roughness of inner wheels
UIC leaflet	813	tolerances and assembly of wheel sets.

In the accident in Baarn, only standard 812-5 is relevant. Because this standard from the Union Internationale des Chemins de Fer dates back to 1988, it was not relevant during the production of the wheel sets, in 1969. Subsequently, it was determined that the broken wheel did comply with standard 812-5. This is despite the fact of a groove in the wheel surface, observed after the accident. This groove occurred during production, in the final machining of the wheel surface, to smoothen the surface. This process was carried out in two stages, one starting by the axle hole, and the other starting at the outside of the wheel. The manufacturer delivered the wheels, and the wheels were accepted and treated as normal, full-quality wheels, without reservation.

As carrier and owner, NS Passengers is fully responsible for Materieel 64 and the wheels which form part thereof. According to the working method deployed by NS Passengers to date, it may be determined that NS Passengers implicitly operates the standard that crack formation in wheels is acceptable, and that such cracks will be discovered in good time, on the basis of specific examination. If such cracks are discovered, the wheel in question is replaced. This is the standard approach for wear parts. Here, it is assumed that checking and inspection will identify in good time when wear parts need to be replaced. Wear parts can be viewed as disposable components. Old parts are replaced by new. No administration is maintained of specific wear parts.

7.2 Cracks and Fractures

Fig. 7 The cracked inner wheel

Investigations by NS Technical Research have demonstrated that a fracture in the inner wheel was the cause of the derailment of Materieel 64 in Baarn. The complete fracture was due to fatigue cracks in the inner wheel. Following the fracture, the train set travelled approximately 1 kilometre further. The bogie was able to keep the broken-off wheel in line, for a short time. During this time, the fracture surfaces continuously impacted upon one another. This resulted in tremendous friction which partially caused the fracture rim to ‘disintegrate’ as a consequence of which the rim is somewhat rounded off.

It has emerged that fatigue cracks in this type of wheel are not isolated. For a considerable time, special equipment has been in use, in tracing fatigue cracks. And cracks have indeed been regularly identified, over time, as shown by the table below, in which, in addition, the lengths of the cracks observed in the wheels are listed.

Table 1. CRACKED INNER WHEELS TYPE 275

Date	Crack lengths (in centimetres)
3 August 84	35, 8
5 February 91	4
14 January 92	all-round
16 April 92	25
29 April 93	10
25 October 95	25, 15
4 January 96	unknown
27 March 97	17
20 August 99	all-round

A graphic reproduction showing for each year the total number of wheels cracked up to that date, provides the following picture:

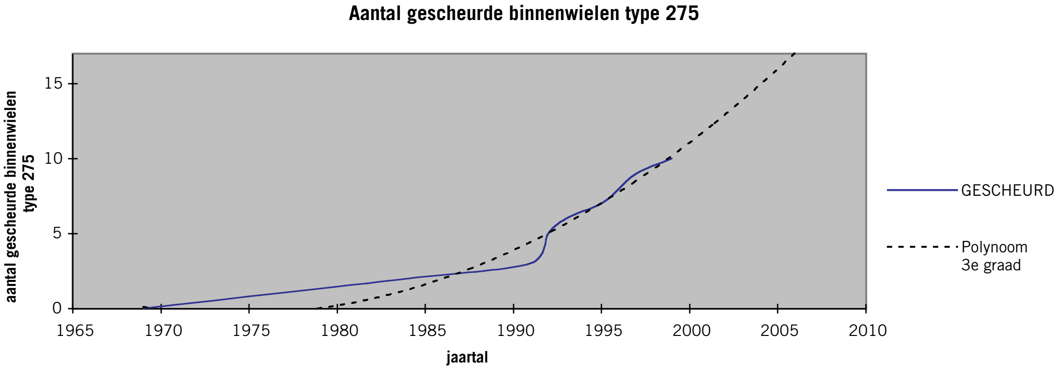

Fig. 8 Taken from the report: History of Wheel set 61 217

NS Technical Research March 2000. The graph shows cumulative data.

The table and graph are disturbing. Both clearly demonstrate that wheels do not have an infinite service life. The number of cracks increases, the closer the end of the technical service life becomes. This is precisely the behaviour of material which in terms of load, is in the difficult to manage zone of figure 6. It is no problem to make constructions in this zone, if two conditions are met: it must be possible with absolute certainty to trace fatigue cracks, and the speed with which the crack is developing must be accurately known.

From the data in table 1, we see that there is little understanding of crack behaviour. For a well-managed process, the cracks are too long and the variation in observed crack lengths too great. The absolute sizes of the cracks, observed during inspection, vary from 4 cm to 35 cm, with a random length distribution over time. In the event of sound inspections, one would rather have expected that crack length would have reduced over time, with the longest cracks having been identified immediately after 1984. In that case, the problem would have been more or less under control. However, this is shown to have not been the case. The cracks observed therefore represent a complex problem. Cracks have also been shown to occur in wheels of other types of wheel set.

7.3 The monitoring process for fatigue cracks

Fatigue cracks indicate the approaching end of the technical service life of the wheel. Monitoring cracks only becomes important after a number of years have expired. The wheel which failed in Baarn was manufactured in 1969. In 1984, a 35 cm crack was discovered for the first time, in a wheel of this type. The crack was found during a special programme in the Haarlem Workshop, now owned by NedTrain. During this programme the wheel sets of type 275 were investigated using specific equipment, which makes use of electrical eddy currents. If the pattern of the eddy currents generated in the wheels deviates from the expected pattern, this is an indication of an irregularity in the material. This irregularity may be a crack. Until 1984, such inspections were not carried out on these wheel sets. On the basis of the report by the then Centre for Technical Research, issued following the crack identified, from 1984 onwards, all wheel sets of this type were examined for fatigue cracks, during every re-tyring. During the re-tyring process, the hardened steel strip around the inner wheel is replaced by a new strip (see fig. 3). Re-tyring is on average carried out once every 7 years. The wheel tyres have then travelled approximately 1,500,000 km. The tyre thickness is then reduced from 7 cm to 3.5 cm. The re-tyring of this stock is only carried out at the Haarlem Workshop.

In 1992, a train consisting of Materieel 64 derailed, in Bodegraven. The cause proved to be an inner wheel of type 275 which failed due to fatigue. The Haarlem Workshop then requested the Centre for Technical Research to examine two other cracked inner wheels of the same type, identified during overhaul work. This Centre issued a report on these wheels, in 1992, with the following conclusion:

> The inner wheel is cracked as a result of fatigue, from the flange side of the wheel. No faults were identified in the inner wheel, which could explain the occurrence of the fatigue. The wheel is probably at the end of its service life.

In respect of the growth speed of the crack, the following comment was made:

> Given the appearance of the fracture surface (flat, flattened), the speed of growth of the crack was not high. The crack growth speed may vary widely from months to one or more years.

Two years following the derailment in Bodegraven in 1994, the inspection period was in fact altered. Instead of a crack investigation during re-tyring (application of new tyres), the period for crack investigation was set in 1994 at once every two years, or during re-profiling. The old inspection period was based only on re-tyring, which equated on average to once every 7 years. During re-profiling, the running surface of the tyre, which either has flat points or is worn due to travel, is returned in the ground wheel-lathe to its original pure round shape. This process is carried out on Materieel 64 in the maintenance workshops.

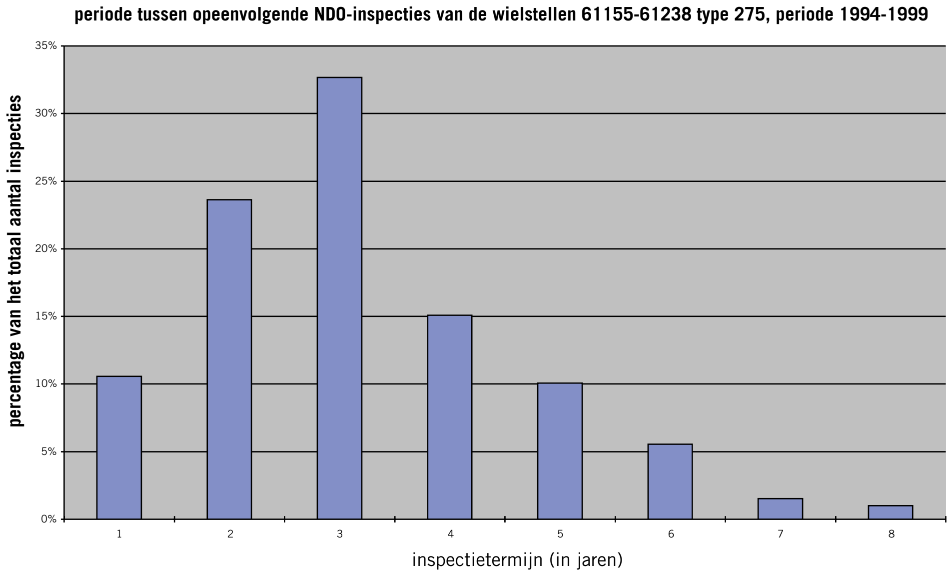

Fig. 9 Percentage distribution of crack investigations carried out broken down according to inspection period between two investigations. Data taken from the report History of wheel set 61 217 NS Technical Research, March 2000.

As shown by the graph, this inspection period, introduced in 1994, has not been achieved. The intention of the procedure was that from 1994 onwards, every wheel would be inspected for cracks at least once every two years. In the period 1994-1999, a total of 199 wheels were investigated for cracks. As the graph shows, of this number 35% (1 year: 11%, 2 years: 24%) were actually investigated within two years. The remaining 65% of these investigations were carried out too late, some of them many years too late.

Flat points can have a major influence on the occurrence of fatigue cracks. The added criterion for crack investigation from 1994: during every re-profiling, was therefore a sound choice. This approach was employed until after the derailment in Baarn. On the basis of an investigation report by NS Technical Research, on 18 March 1999, the decision was already taken to increase the investigation frequency. However, this alteration had not been introduced on the shop floor. Finally, it should be noted that the monitoring process for wheel sets of all stock is based on the wear part concept. Cracks have been identified in inner wheels, not only on Materieel 64. Investigations have shown that cracking also occurs in other wheel sets. Wheels are replaced at the moment that a crack is identified. Precisely the same happens with a broken window. Both are viewed as wear parts. The most obvious method of monitoring wheels: recording the number of fluctuations in load for example by recording the number of kilometres travelled, has still not been introduced, to date.

7.4 Implementation of crack investigations

Various methods are available for identifying internal defects, in constructions such as wheels. At NedTrain, for tracing defects in wheel discs, the Förster Defectometer has been chosen, which operates on the basis of the eddy current method. In the material to be investigated, an electrical eddy current is generated. If the eddy current generated in the material to be investigated deviates from the expected current, the apparatus issues an acoustic signal. The deviation, bringing about a signal, must be regularly calibrated. For this investigation, the system is set to a reference crack with a depth of 4 millimetres. This dimension seems generous. The section of the wheel to be investigated is approximately 25 mm thick. The dimension of the reference crack selected would seem to be based on a rejection dimension. If, for example, 1 mm were chosen for the reference cracks, far more cracks would be detected. This would result in far more information about the fatigue behaviour of wheels. The rejection dimension need thereby not necessarily be immediately altered. Because far more cracks would then be found, the investigation process would also be far better, in ergonomic terms.

The apparatus works using a sensor. This sensor must be moved radially, in increments of 2 cm, across the wheel surface. Investigations into implementation, such as carried out at the workshops in Amsterdam and Haarlem, demonstrated that implementation is subject to numerous deviations from the regular working method. Instead of increments of 2 cm, increments of 5 cm also occur in the process. The calibration of the appliance is either not carried out, or only marginally. Further, an investigation of this type is itself problematic. Ergonomic studies have demonstrated that a human being is not particularly suited for carrying out monotonous 'low stimulus' activities. It is practically unavoidable that errors will be made. The investigation using the Förster Defectometer shows these characteristics, to a high degree. Every wheel must be radially investigated, in increments of 2 cm. For every wheel, this represents a large number of hand movements. In the process, the sole reference for the service engineer carrying out the investigation, in terms of the position of the sensor on the wheel, is the track left by the sensor in the dust present on the wheel surface. In the total number of increments or movements carried out, the service engineer rarely finds a crack. In other words, monitoring wheel surfaces with a sensor, by hand, is not a watertight system for tracing defects in the wheel.

In the Haarlem workshop, bogies and wheel sets are overhauled. This means they are dismantled. The service engineer carrying out the investigation is then able to access the wheel, easily, from all sides. At least far better than in the maintenance company, where the investigation into cracks must be carried out on a wheel set still attached to a train. It is therefore no surprise that the maintenance company has never discovered a crack in the wheels of type 275 wheel sets, which form part of compact motor bogies.

7.5 Certification

In 1999, NedTrain, the company responsible for carrying out maintenance for NS Passengers, was certified as a maintenance company by Railned, and hence also by the government. According to Directive M-004 of Railned, the following aspects were observed:

- The validity of the maintenance concept employed
- Quality control
- Skill of the personnel
- The tools, equipment, materials and measuring instruments employed.

By issuing this certificate, the government indicated that the maintenance of rail vehicles is in good hands, at NedTrain. Investigations have shown that this is certainly not the case, for one aspect crucial to safety, in particular the fatigue investigation of specific wheels. Railned, the certifying body, has indicated that in their assessment of this 'high-tech' company, they above all evaluated the presence of a smoothly functioning safety system, in accordance with the ISO-9000 approach. In addition, the content of the work descriptions and the implementation of the technical processes was randomly tested. For incidental certification, it is quite simply not efficient and practically impossible to substantively evaluate the huge number of very advanced technical processes carried out by NedTrain. In this respect, standard M-004 is clearly deviated from.

This problem is not new. Every supervising body is faced with it. The manpower which must be employed in assessing a company is always limited. The intensity and quality of this assessment process depend on the specific manpower deployed, and the available technical knowledge. The consequences linked by government to this assessment should match and equate to the efforts made. The overall recognition by Railned and thus also by the government of NedTrain, as maintenance company according to standard M-004, is a far-reaching step. By taking this step, the signal was issued to NS Passengers, that the maintenance process was in good hands at NedTrain, in every respect. On this basis, it is at least suggested that the Management of NS Passengers can leave the maintenance of its stock entirely to NedTrain, without risk, and without further monitoring by NS Passengers. The marginal assessment such as that carried out by Railned, which encompasses only a limited proportion of the overall package described in the standard M-004, represents a poor foundation for the issuing of such a signal.

7.6 Conductor and supervision

There was no conductor on the train. One of the consequences of this fact was that the passengers had to follow the track to Soestdijk station, without supervision. As demonstrated by this incident, in the event of accidents, the conductor has important tasks. Driving without a conductor is viewed as normal working practice. On the Zoetermeer line, trains have travelled without a conductor, right from the start. The absence of the conductor in this case did not result in specific hazards. However, having passengers follow the track must be prevented. Access to the railway track is and remains forbidden. This simple safety measure must not be violated. In the given circumstances, the driver involved was able to responsibly organise the passengers following the track. However, there are numerous locations, for example on four-track sections, and on railway bridges, where this is absolutely not possible. In such circumstances, the conductor has an essential safety task. It would therefore seem desirable to further consider circumstances according to which the presence of the conductor is necessary, for safety reasons.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

In rail traffic, it has been assumed that trains will not spontaneously derail. Given the current intensive use of the network, and the large number of physical obstacles in the immediate vicinity of the track, derailments can lead to almost unimaginable consequences. Because such a situation is inadmissible, the requirement must be imposed that carriers guarantee the safe running of their rolling stock.

The derailment of the NS Passengers train in Baarn, on 20 August 1999, demonstrates that there is no such guarantee. The derailment was caused by a wheel fracture. The wheel in question broke as a consequence of fatigue cracks, initiated from a manufacturing groove. Crack formation in inner wheels of passenger trains is accepted by NS Passengers. The management of NS Passengers is conversant with the formation of cracks in inner wheels of Materieel 64 and other stock. The speed of crack growth in inner wheels of type 275 is not known, the method of tracing cracks, as currently implemented, is not reliable, and the period within which inner wheels must be investigated is structurally exceeded. The service life of inner wheels is not based on kilometre performance, although this would be the most obvious monitoring instrument. The investigation has demonstrated that NS Passengers has not ensured the responsible maintenance of inner wheels of type 275 wheel sets. If fatigue cracks occur, NS Passengers must assure and ensure that maintenance is systematically and structurally carried out.

In 1999, in accordance with standard sheet M-004, Railned issued the NedTrain workshop in Haarlem the title “Approved maintenance company for railway stock”. This standard represents an overall assessment of all processes carried out at the company. The maintenance process of inner wheels is not structurally and systematically organised by NedTrain, and is insufficiently managed. The approval is therefore based on insecure assessment.

8.2 RECOMMENDATIONS

The Management of NS Passengers is recommended, in the shortest possible time, to guarantee the safe running of Materieel 64, by:
increasing the reliability of the rapid tracing of fatigue cracks in inner wheels;
determining the speed with which cracks develop;
complying with the periods laid down for crack investigations.

If NS Passengers fails to guarantee safe running, according to these measures, it is recommended that at least all inner wheels on type 275 bogies be replaced.

The Management of NS Passengers is recommended to develop a maintenance strategy for all passenger stock, guaranteeing the safe running of this stock, at all times.

The Minister of Transport, Public Works and Water Management and Railned are recommended to reconsider the policy instrument of compulsory certification of maintenance companies in combination with the standard M-004, which calls for assessment of all business processes.

OVERVIEW OF PART INVESTIGATIONS

The final report is based on the following part reports, prepared under the auspices of the Council for Transport Safety. The part reports in particular provide explicit descriptions of the various facts (operational, technical, organisational). The part reports are available on request.

- Investigation into Derailment of train 5558 in Baarn
  Part report dated February 2000, Fact finding
  By the Council for Transport Safety / Railned

- Investigation into Derailment of train 5558 in Baarn
  Part report dated 2000, Management process
  By the Council for Transport Safety / Railned

- Investigation into Derailment of train 5558 in Baarn
  Part report dated 2000, Frameworks and rules
  By the Council for Transport Safety / Railned

- Investigation into Derailment of train 5558 in Baarn
  Part report dated 2000, Material damage
  By the Council for Transport Safety / Railned

- Investigation into Derailment of train 5558 in Baarn
  Part report dated 2000, Risks
  By the Council for Transport Safety / Railned

- Investigation into Derailment of train 5558 in Baarn
  Part report dated 2000, Conditions
  By the Council for Transport Safety / Railned

- Investigation into Derailment of train 5558 in Baarn
  Part report dated 2000, Countering consequences
  By the Council for Transport Safety / Railned

- Damage investigation, inner wheel 61217 type 275
  NS Technical Research, October 1999
  Carried out on behalf of the Council for Transport Safety

- Reconstruction of derailment, passenger train 5558
  NS Technical Research, November 1999
  Carried out on behalf of the Council for Transport Safety

- History of wheel set 61217
  NS Technical Research, March 2000
  Carried out on behalf of the Council for Transport Safety

- Process investigation wheel sets
  NS Technical Research, March 2000
  Carried out on behalf of the Council for Transport Safety

- Computer simulation Derailment Baarn
  NOB / NS Technical Research, March 2000
  Carried out on behalf of the Council for Transport Safety