RAIL ENGINEERING INTERNATIONAL

Combating rolling contact fatigue: strategies adopted in The Netherlands

Since 2001, ProRail has been actively investigating the causes of rolling contact fatigue (RCF) and, in close collaboration with Netherlands Railways (NS) and NedTrain, has developed strategies to reduce its occurrence. This article looks at the practical approach adopted by ProRail towards managing RCF. First, a short introduction is given of ProRail's track management approach. Then, the dramatic increase in the occurrence of RCF on the Dutch railway network and the countermeasures adopted are addressed.

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PRORAIL'S TRACK MANAGEMENT APPROACH

ProRail is the Infrastructure Manager for the Dutch railway network, under a Management Concession granted until 2015. ProRail carries responsibility for design and new construction, maintenance, renewal, capacity allocation, as well as traffic management. As such, it manages one of the most intensely used railway networks in Europe. Every day, some 1.2 million passengers and 100,000 tons of freight are transported on nearly 7,000 km of railway line. Netherlands Railways (NS) is the largest train operating company using the network, responsible for some 80% of passenger train km. However, there has also been a steady increase in the number of regional and freight train operating companies (to 36 in 2009). New train operating companies are able to enter the railway network after rolling stock acceptance, which is managed by the Transport & Water Management Inspectorate, and the allocation of slots according to non-discriminatory procedures. Infrastructure use is charged on a variable cost basis, which includes the tonnage borne by the infrastructure. The tonnage borne is constantly monitored by the "Quo Vadis" weigh-in-motion (WIM) systems that are located at strategic points on the network and capture practically all traffic movements in real time.

The track, turnouts and level crossings belong to the critical assets of ProRail, as is the case for each Infrastructure Manager. Failing track, such as rail breakages and defect insulation joints, and turnouts make train operation impossible or require the implementation of speed restrictions (e.g. 40 km/h). The track assets of ProRail have a replacement value of about EUR 8 billion (out of the about EUR 30 billion for the total system) and, each year, their upkeep accounts for a significant share (up to 60%) of the total maintenance costs, due to their usage-based, relatively rapid deterioration pattern. The standard track system consists of 54E1 rails on concrete monoblock sleepers and a 30 cm thick ballast bed. The new Betuweroute and the High Speed Line South feature 60E1 rails.

Turnouts are relatively complex, failure-prone systems, which is why standardisation is being strived for. On the Dutch railway network, standard ratios of inclination for turnouts are 1:9, 1:12, 1:15, 1:18.5 and 1:34.7. Often, special engineering solutions are required at railway yards, due to the limited space available (e.g. double-slip turnouts).

Track management

ProRail manages its track assets according to the model shown in Fig. 1. Performance data is collected, summarised and monitored at several levels. For instance, overall track geometry quality is indicated by a single KPI (key performance indicator) figure for sections of track, but also at detailed levels so that it can be linked to specific maintenance activities.

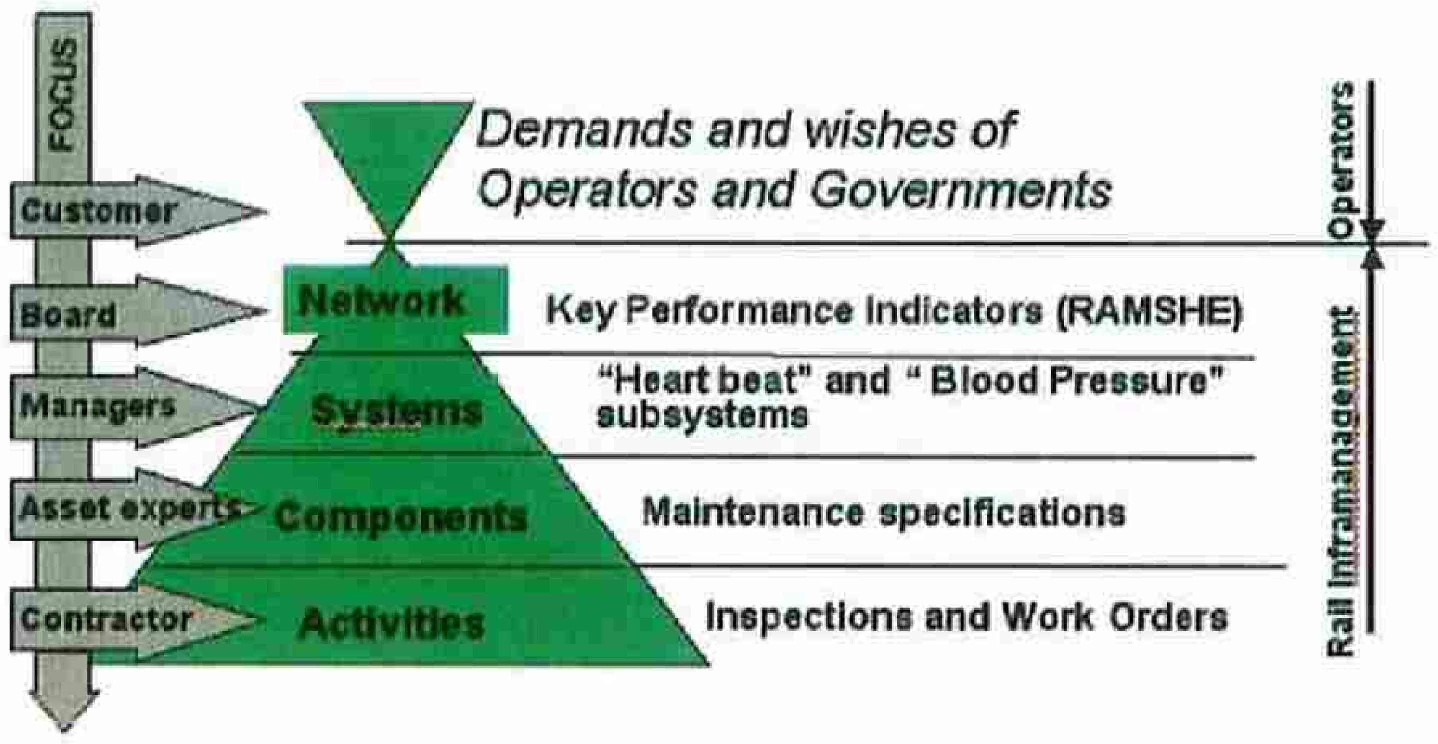


Fig. 1: Performance of track management in four coherent layers (RAMSHE: Reliability, Availability, Maintainability, Safety, Health, Environment)

A considerable part of the maintenance process has been outsourced to contractors, who can now enter the maintenance market through public tendering procedures. The contractor manages a maintenance area for a certain number of years and commits itself to achieve a certain performance/output level during this time period. Thus, the level of output achieved during the contract period is critical for the success of the contractor and the sustainability of the 'cooperation' between ProRail and the said contractor. The contract can be terminated in case of poor performance.

During the contract period, quality checks are made and performance data is being shared between ProRail and the contractor through agreed procedures and tendering requirements. For specific safety-critical activities, ProRail specifies in more detail its requirements and even methods of working. For example, inspection intervals and data collection are issues that are not decided by the contractor, but are determined by ProRail's Asset Management Department and then, to a large extent, the data collected is uploaded into joint viewing systems.

INCREASE IN THE OCCURRENCE OF RCF

It can be said that, after the restructuring of the former NS holding, in 1997, wheel/rail interface management was not given proper attention. At the time, NS was preparing to become a stock-market company, which led to short-term optimisation of their internal processes. ProRail did not exist at the time, but instead there were three separate 'task organisations' on the infrastructure side that worked under the auspices of the Ministry of Transport & Public Works, which were later integrated into ProRail. The execution of maintenance was already outsourced to contractors, but the way in which the contracts were to be organised and managed still needed to be developed. A strict regime of prescribing maintenance activities as they used to be done previously was maintained. Only gradually, over the course of many years, contracts have become more output-based and subject to public tendering. This has been significantly different from the outsourcing strategy followed in the UK which, at the time, was seen by many as an example for Europe.

In 2000, the Hatfield accident in the UK showed that things had changed in the wheel/rail interface and that its management needed attention. Also, at the time, in The Netherlands, measurements conducted using the ultrasonic rail inspection train showed an increase in the occurrence of a new phenomenon, rolling contact fatigue (RCF), which had been known for a long time in other parts of the world (e.g. North American heavy-haul railways).

Initially, RCF occurred in the form of so-called headchecks, which many European railways have become familiar with and, later on, in the form of squats. Since 2001, ProRail has been actively investigating the causes of RCF and has developed strategies to reduce its occurrence [1]. It has become clear that the causes for the sudden increase in the occurrence of RCF are multiple (such as the introduction of trains with a higher seating capacity, an 8-10 times increase in bogie yaw stiffness (e.g. double-deck intercity trains)). In Fig. 2, changes with respect to both wheel and rail that have contributed to the increase in RCF defects are shown. Strategies and countermeasures have been adopted to combat RCF from the side of both the rail and the wheel.

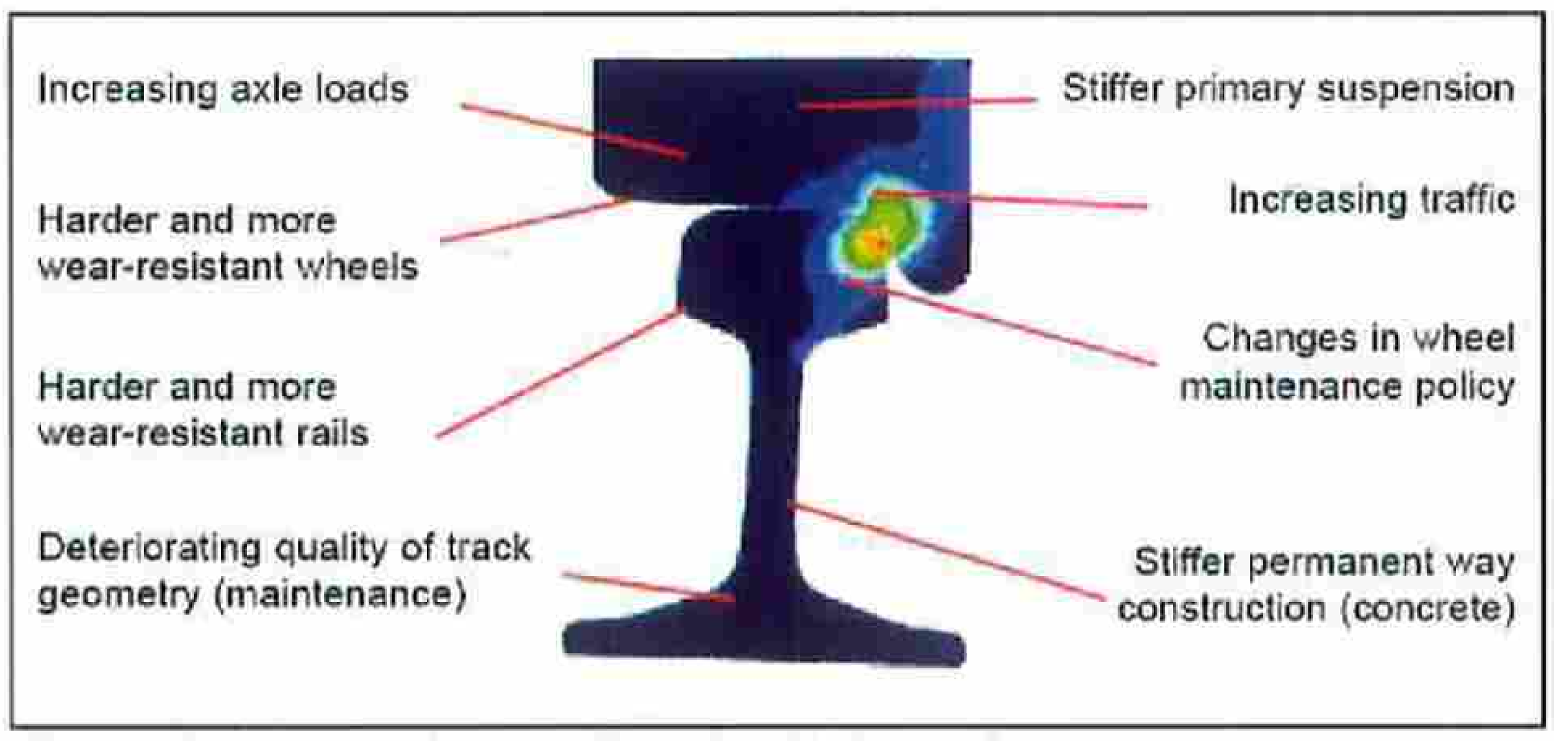


Fig. 2: The typical changes that wheel/rail interface has experienced in The Netherlands

COMBATING RCF FROM THE SIDE OF THE RAIL

ProRail has implemented the following strategies to combat RCF from the side of the rail:
— improvement of RCF detection;
— implementation of preventative rail grinding;
— introduction of an anti-headcheck rail profile;
— coordinated planning of rail maintenance.

Improvement of RCF detection

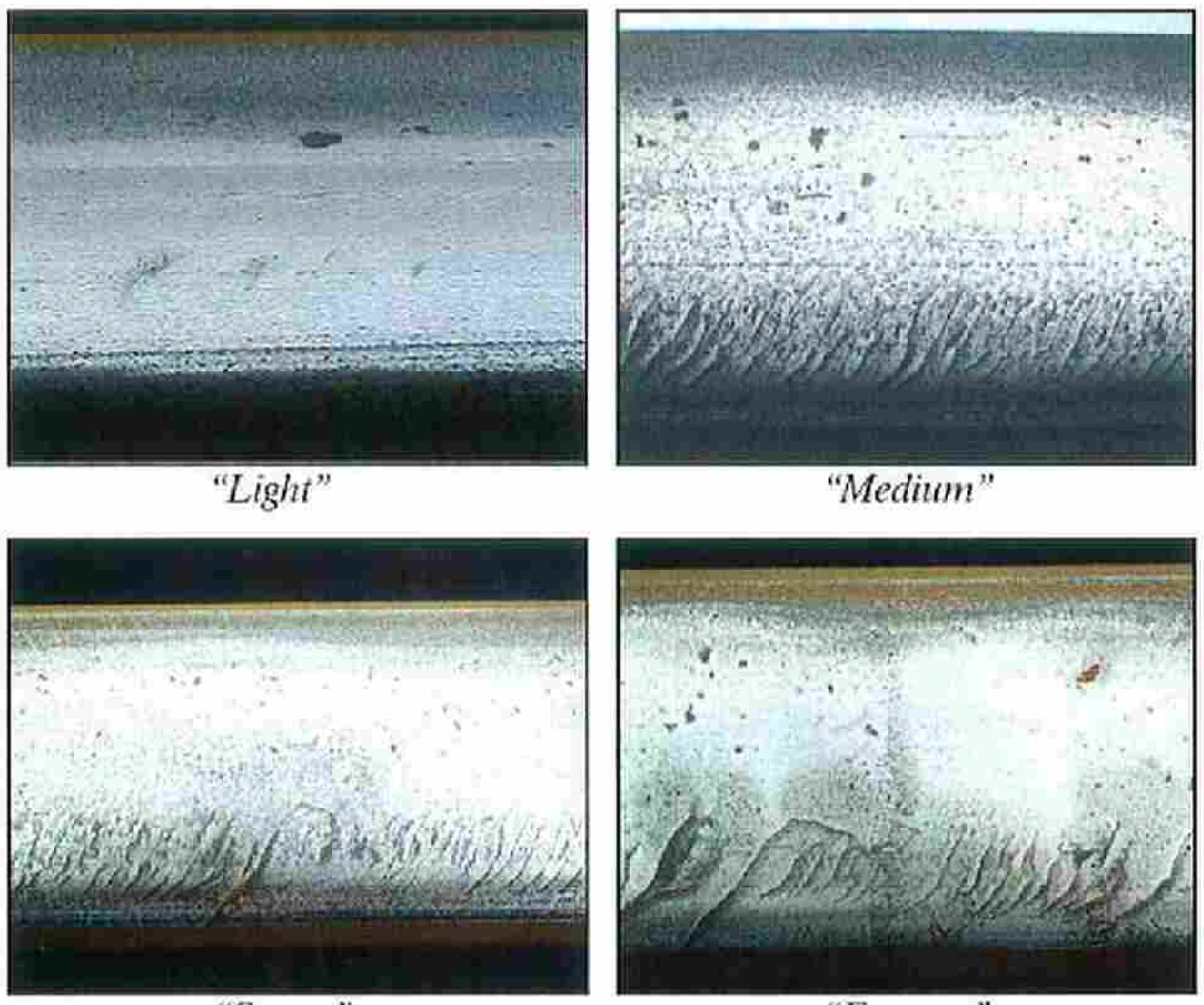
After the RCF problem had been sufficiently recognised, in which also the Hatfield accident in the UK, referred to earlier, played a role, ProRail developed strategies and procedures for dealing with RCF. The initial strategy was to improve the detection of RCF by adopting better inspection techniques (e.g. improvement of ultrasonic rail inspection and adoption of new techniques, the latest development being eddy-current technology) and to renew sections of rail needing replacement, in order to get the track into a certain basic condition. RCF defects are initially identified by a rail inspection train, using ultrasonic and eddy-current technology. Elements of the track that are not measurable by the rail inspection train (such as points, etc.) need to be measured by manual devices.

In The Netherlands, until 2009, RCF inspection campaigns (by ultrasonic rail inspection train and, in parallel, visual inspections) were conducted twice a year. Since 2009, inspections by the ultrasonic rail inspection train are conducted at least twice a year to up to four times a year, depending on track classification according to UIC Leaflet 714 [2]. There where inspections are not conducted by the ultrasonic rail inspection train, twice a year, visual inspections are conducted.

In The Netherlands, headchecks are categorised into four defect severity classes and squats into three (see Table below and Figs. 3 and 4).

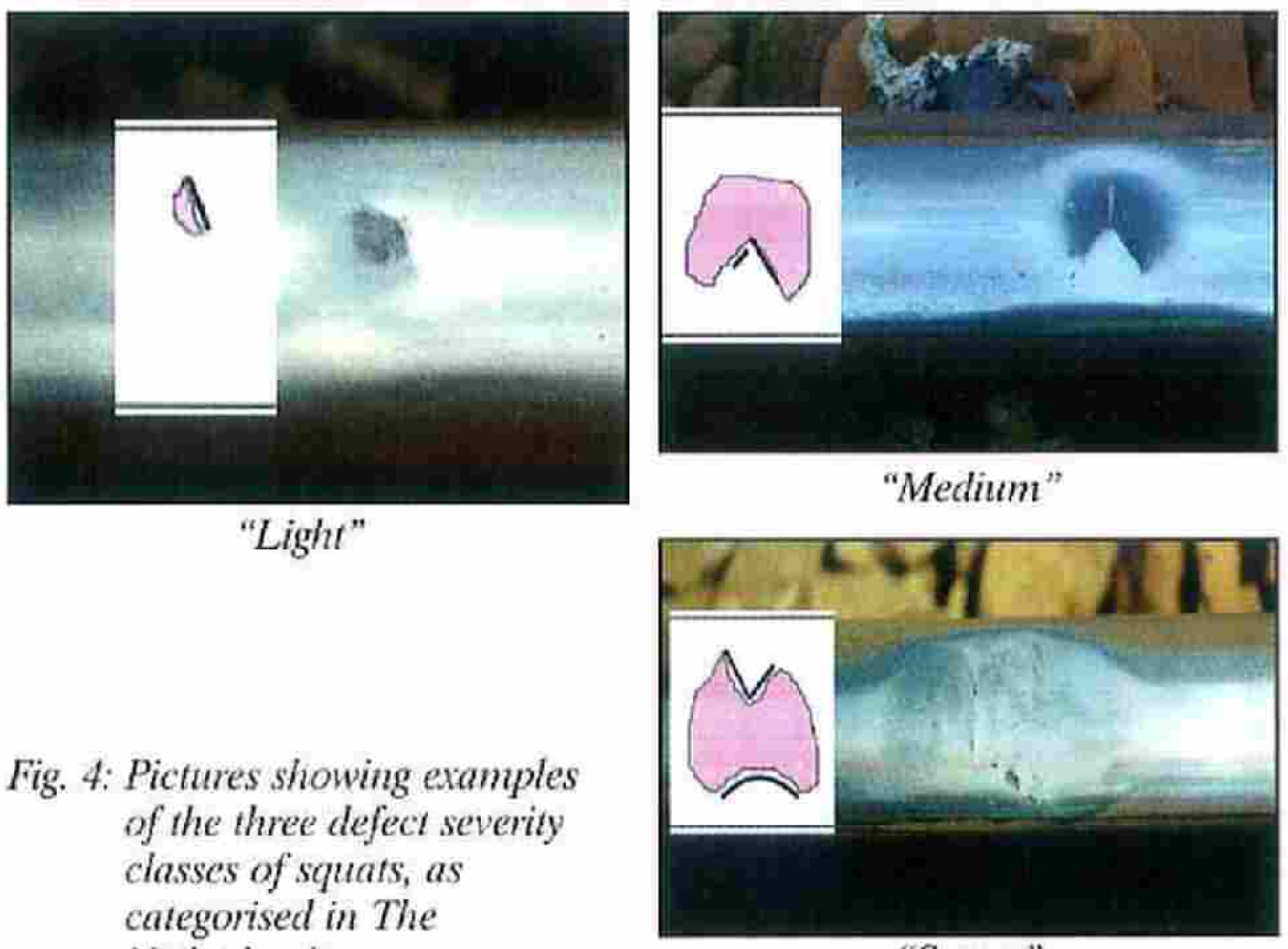
Type of RCF	Defect severity	Abbreviation	Description
Headchecks	Light	L	Surface crack <10 mm
	Medium	M	Surface crack 10-19 mm
	Severe	Z	Surface crack 20-29 mm
	Extreme	ZE	Surface crack >30 mm
Squats	Light	A	A simple imprint in combination with a blackspot
	Medium	B	A 'V-shaped' crack with a blackspot on both sides
	Severe	C	A crack, 20-29 mm long, in combination with a dented rail head and a big blackspot

RCF defect severity classes as categorised in The Netherlands (if RCF is visually detected, a 50 m section of rail is considered "RCF-affected", regardless of the extent of RCF in the section)



"Light" "Medium"
"Severe" "Extreme"

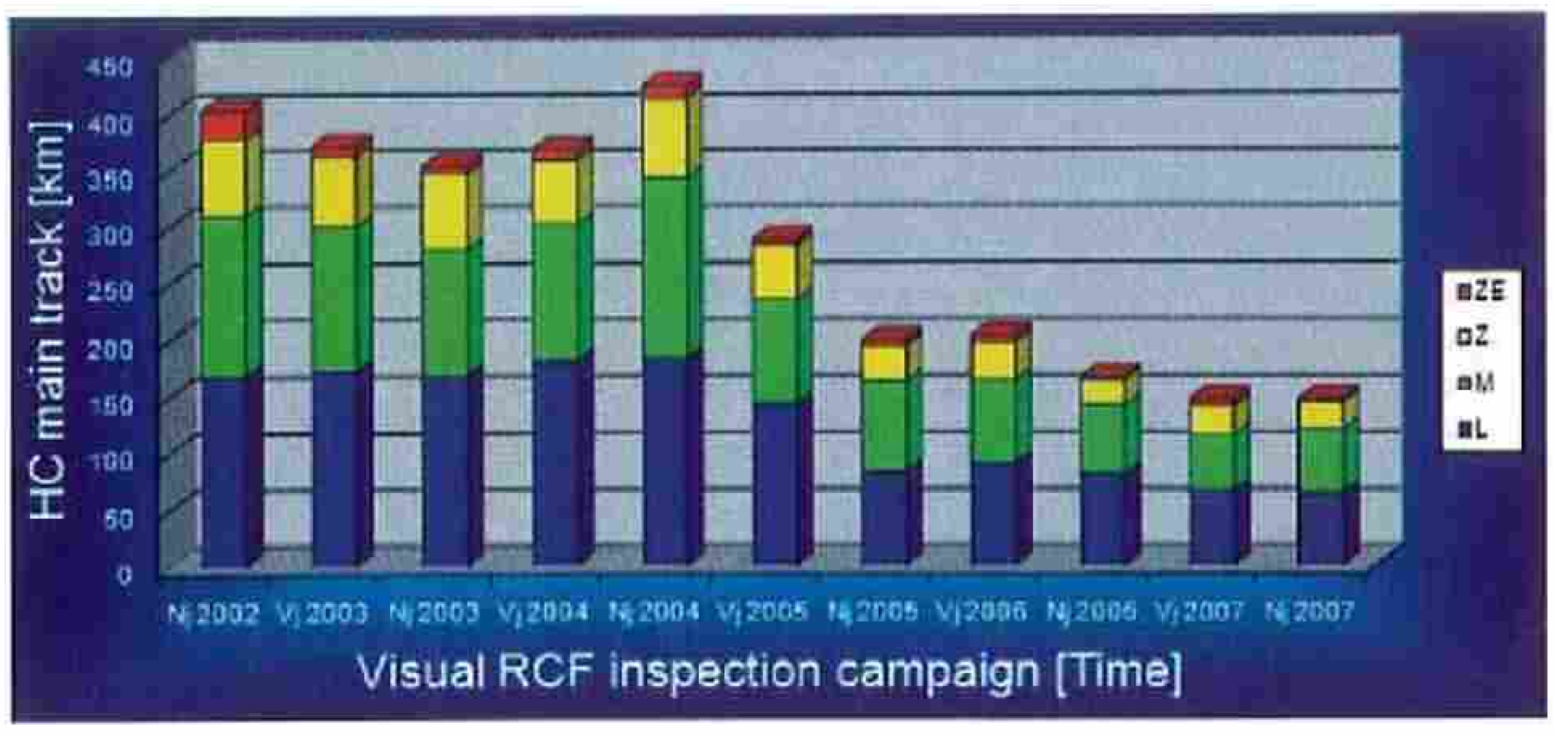
Fig. 3: Pictures showing examples of the four defect severity classes of headchecks, as categorised in The Netherlands



"Light" "Medium" "Severe"

Fig. 4: Pictures showing examples of the three defect severity classes of squats, as categorised in The Netherlands

Improvement of RCF detection has played a significant role in successfully reducing its occurrence in absolute numbers (see Fig. 5). In Fig. 5, also the development in the occurrence of RCF since 2004, when preventative rail grinding was introduced, can be observed.



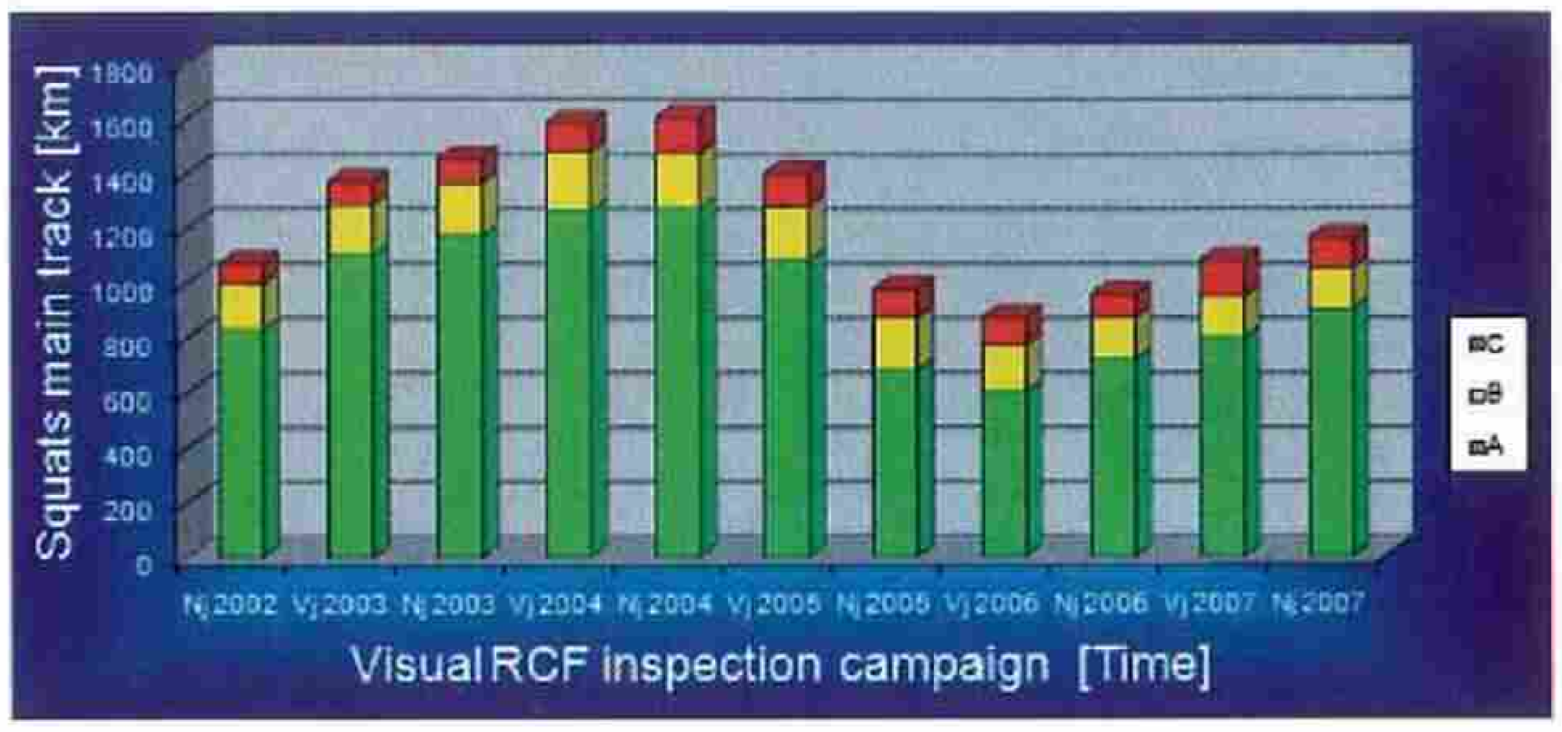


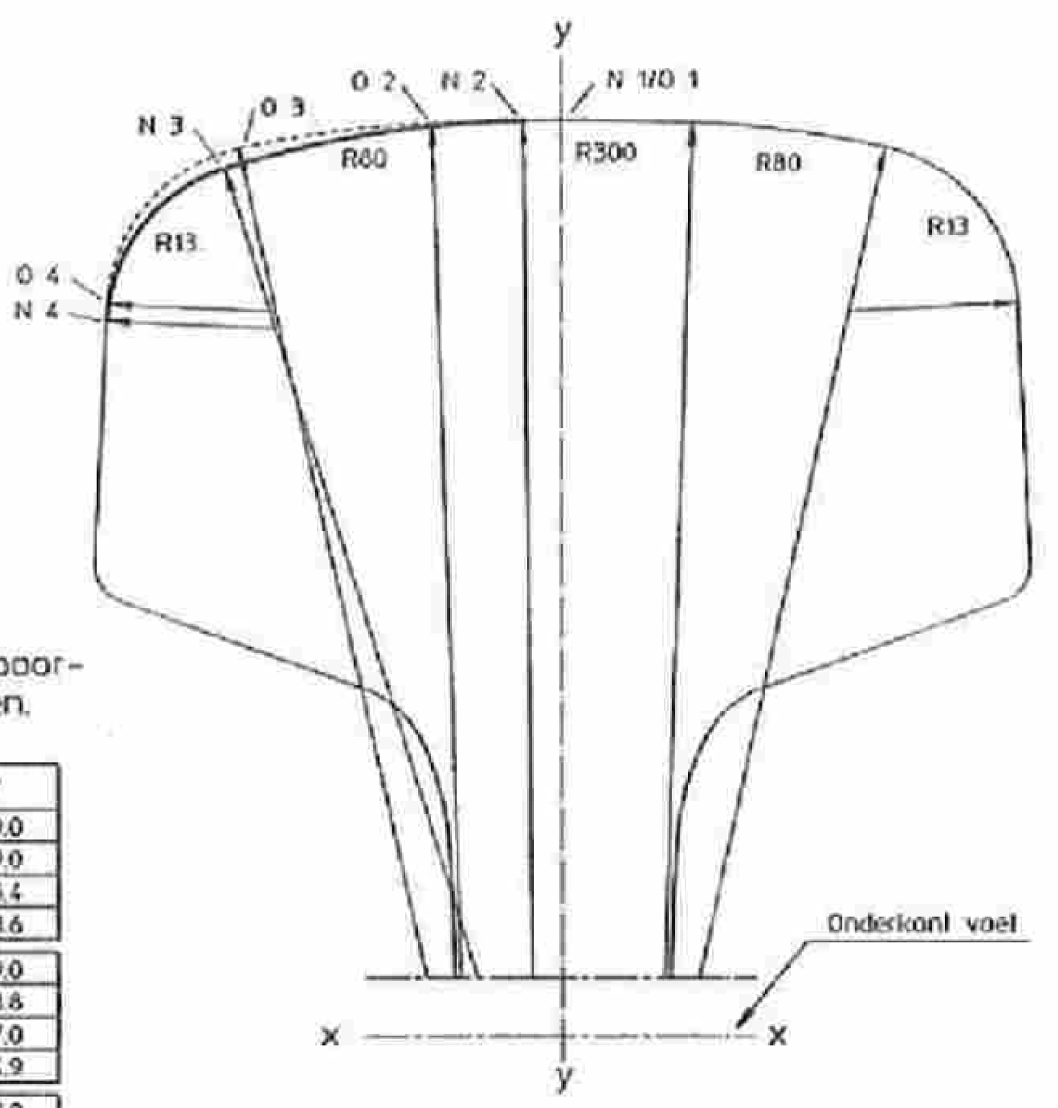
Fig. 5: Reduction in the occurrence of RCF (2000-2007). In The Netherlands, until 2009, RCF inspection campaigns were conducted twice a year (i.e. in the spring "vj" and in the autumn "nj") to determine the presence of headchecks (left) and squats (right) [3]

Implementation of preventative rail grinding (Fig. 6)
Rails are subjected to a 'Stress Regime' (i.e. high friction and loads resulting from the passage of trains) which, if no countermeasures are undertaken, leads to RCF and, thus, a shorter service life of the rail [4]. Once damage occurs, the deterioration process of the rail accelerates. This process can be slowed down by grinding an artificial wear profile and introducing a 'Wear Regime', whereby headchecks in their initial stages are eliminated and, thus, have no opportunity to develop into deep defects.

In The Netherlands, preventative rail grinding was implemented in 2004 (pilot phase) and 2005 (national roll-out), with different grinding intervals for different loads and curve radii - directly adopted from Canadian heavy-haul practice [5]. It took a number of years to get the entire railway network into a certain basic condition, after which more limited grinding intervals and depths could be adopted, which was the case in 2008. The preventative rail grinding strategy adopted has led to a 75% reduction in the occurrence of the most severe category of headchecks on straight track: i.e. from 25 km affected with severe headchecks in 2002 to 5 km in 2007.

The business case for the preventative rail grinding strategy was strong from the start. It was estimated that, considering only direct RCF maintenance, each EUR 1-00 invested in preventative rail grinding would bring more than EUR 3-00 in return. Preventative rail grinding also leads to a reduction in the occurrence of corrugations, as better wheel/rail contact properties and reduced dynamic forces are achieved which, in turn, leads to an increase in the service life of the rail.

Fig. 6: The implementation of preventative rail grinding in The Netherlands has contributed to a significant reduction in the occurrence of RCF



Coördinaten beloop spoorstaafkop en stralen.

nr	x	y
N 1	0	159.0
N 2	-3	159.0
N 3	-26.0	155.4
N 4	-35.1	143.6
O 1	0	159.0
O 2	-10.0	158.8
O 3	-24.9	157.0
O 4	-35.0	144.9
N R13	-22.1	143.0
N R80	-2.2	79.0
N R300	0	-141.0
O R13	-22.1	144.2
O R80	-7.3	78.9
O R300	0	-141.0

N is anti-headcheck profiel
O is normaal profiel

Fig. 7: The Dutch "Anti-Headcheck" rail profile 54E1

Introduction of an Anti-Headcheck rail profile
A research programme into RCF, in which the Delft University of Technology, Lloyd's Register Rail and DeltaRail participated, has led to the standard use of a so-called "Anti-Headcheck" rail profile in curves with a radius R < 3,000 m since 2005 and, since 2006, also in turnouts (Fig. 7). Further, different rail steel qualities are applied, depending on location. Currently, studies into new types of rail steel, e.g. Bainite, and scientific research into the initiation of squats are underway (the occurrence of squats is a matter of major concern. Although increased knowledge has been obtained in the last few years with respect to their initiation and growth development, in order to get a grip on the prevention of squats, more research will be needed).

Coordinated planning of rail maintenance
In The Netherlands, the total annual costs of all rail maintenance activities related to the control of RCF still amounts to more than EUR 50 million. Managing the RCF problem efficiently and cost-effectively requires an overall coordination of RCF mitigation measures and rail renewals, as well as an efficient approach by the inspection, maintenance and renewals departments. ProRail has re-engineered its RCF treatment procedures and defined clear roles and responsibilities.

After a first pilot project in one of its regions (in 2004, when about 40% of the rails were affected by RCF), ProRail has developed a specific process for defining RCF maintenance plans. Now, a number of coordinators are working in the regional offices of ProRail to align RCF inspection and maintenance activities with planned rail (section) renewal activities. Also, a guideline document has been developed to deal with RCF in a cost-effective manner, which entails the adoption of the right maintenance activity at the right time, i.e. repair welding and grinding when possible, and renewal when necessary. Costs of grinding are approx. 5% of those of rail renewal.

COMBATING RCF FROM THE SIDE OF THE WHEEL
In 2007 and 2008, further steps were taken to "combat" the headcheck problem at source, by avoiding the exertion of unnecessary load and friction onto the track. It was recognised that wheel and rail are subjected to similar RCF problems, as there is a relationship between wheel and rail in the obvious sense: the wheel being in constant contact with the rail. This means that changes to the wheel profile, the material used and maintenance would also have an influence on the rail.

Optimising wheel maintenance, as well as adopting a more "track-friendly" design, contributes to an increase in the service life of both wheel and rail (see also [6], for more details). Based on this "train of thought", in The Netherlands, the wheel/rail interface has not only been optimised from the side of the rail but also from that of the wheel.

The following strategies have been implemented to combat RCF from the side of the wheel:
— optimisation of the wheel profile;
— optimisation of wheel reprofiling intervals.

Optimisation of the wheel profile

Until 2005, the UIC-ORE S1002 wheel profile was used for all passenger trains in The Netherlands, which was developed in the 1970s. Since that time, railways have seen significant changes. Heavier axle loads and increased bogie yaw stiffness have been introduced, which has resulted in new problems, among which the occurrence of RCF. Optimising the wheel and/or rail profile is one way to reduce the occurrence of RCF. A logical approach would be to optimise both wheel and rail profiles. However, as this is such a complex problem, in The Netherlands, first the rail profile was optimised separately, based on the principle that the gauge corner of the rail should be relieved, which resulted in the "Anti-Headcheck" rail profile mentioned earlier. Subsequently, based on this "Anti-Headcheck" rail profile, the wheel profile was optimised, the goal being to reduce slip forces and increase the wheel/rail contact area. This resulted in the development of the so-called "HIT" wheel profile, which has been adopted for intercity trains. Wheels of suburban trains are still re-profiled with the S1002 profile, as these trains have low axle loads and a low bogie yaw stiffness.

Adopting the "HIT" wheel profile has led to a significant decrease in the occurrence of RCF cracking and flange wear of the wheel, which has resulted in an increase in the service life of the wheel of up to 30%. As the additional costs of turning a different wheel profile are minimal, a cost reduction of the same magnitude has been achieved. The impact of this alternative wheel profile on the occurrence of RCF on the rail is not known exactly. However, as noted earlier, one of the aims of the alternative wheel profile was to reduce slip forces; this means that what is beneficial for the wheel will also be beneficial for the rail.

Optimisation of wheel reprofiling intervals

Based on a life-cycle cost (LCC) analysis for wheelset maintenance, for certain train types, the wheel reprofiling intervals have been successfully optimised. It entails that, at fixed intervals, all wheels are planed preventatively, whereby about 1 mm (in depth) of metal is removed (this small metal removal rate results in a slower development of wheel out-of-roundness). By adopting this preventative wheel planing, defect initiations, such as small cracks and pitting, are removed at an early stage, thus avoiding further damage. It also results in a longer service life of the wheel, as compared to condition-based planing. Investigations are underway to determine whether preventative wheel planing at fixed reprofiling intervals should also be adopted for other train types, instead of the condition-based approach.

Preventative wheel planing also has a significant benefit for the rail: the increased smoothness of the wheel surface achieved significantly reduces the dynamic load exerted on the rail.

Preventative wheel planing, together with the use of the "QuoVadis" weigh-in-motion (WIM) system, has resulted in a reduction in the number of rail defects resulting from the operation of NS trains.

CONCLUSIONS

As shown in this article, ProRail has, in close collaboration with NedTrain and NS, developed a comprehensive approach to deal with risks and cost impacts of RCF, which has led to a clear reduction in the occurrence of RCF, as well as an increase in the service life of both rail and wheel. So far, the preventative rail grinding strategy and "Anti-Headcheck" rail profile adopted have been highly successful in improving wheel/rail contact properties, reducing the occurrence of RCF defects and, thus, extending the service life of the rail.

All in all, it can be stated that RCF management in The Netherlands has been effective, thanks to a combination of measures (see also [7]):
— implementation of preventative rail grinding;
— optimisation of RCF-related rail maintenance and renewal (repair welding and grinding when possible, and renewal when necessary);
— adoption of high-strength rail steel and the "Anti-Headcheck" rail profile;
— a thorough understanding of the causes of RCF through scientific research;
— adoption of improved RCF inspection techniques (e.g. eddy-current technology);
— adoption of the optimised "HIT" wheel profile and wheel reprofiling intervals.

However, as railways in Europe are more and more becoming an open system with many actors involved, it is not a time to rest on one's laurels. For example, new and different vehicle types will be designed and cross national borders, the impact of which on the track needs to be controlled. An example of providing the right incentives for vehicle design and use is the damage-based access charges of Network Rail in the UK for bogie yaw stiffness.

Further scientific research into the wheel/rail interface will remain necessary, in order to determine other damage factors, find respective remedies and achieve closing of "open points" in the European Technical Specifications for Interoperability (TSIs) related to the wheel/rail interface.

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