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Railway infrastructure condition-monitoring and analysis as a basis for maintenance management

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Professional paper

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Railway infrastructure condition-monitoring and analysis as a basis for maintenance management

Average annual maintenance and renewal (M&R) expenditures per 1 km of tracks of advanced railway networks nowadays revolve around EUR (€) 50.000. Estimated cost-savings resulting from the use of a modern condition-based decision-making approach, embedded in a suitable decision-support information System, are reported to range from modest 15 % up to the optimistic 55 %. Most important railway track condition-monitoring methods applied worldwide are described, and a data analysis process used for the M&R management purposes is presented.

Key words:
railway infrastructure, management, maintenance, track condition measurements

Stručni rad

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Mjerenje i analiza stanja željezničke infrastrukture kao osnova za upravljanje održavanjem

Suvremene željeznice danas troše oko pedeset tisuća eura na godinu po kilometru kolosijeka za održavanje i remont. Uštede koje se mogu postići pomoću suvremenog odlučivanja zasnovanog na mjerenju i analizi stanja, primijenjenog kroz adekvatni informacijski sustav za podršku odlučivanju, procjenjuju se u rasponu od skromnih 15 % do optimističkih 55 %. U radu se daje opis najznatnijih metoda za mjerenje stanja željezničke infrastrukture u primjeni danas u svijetu, kao i opis procesa analize izmjerenih podataka radi upravljanja radovima na održavanju i remontu.

Ključne riječi:
željeznička infrastruktura, upravljanje, održavanje, mjerenje stanja kolosijeka

Fachbericht

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Auf Zustandsmessungen und Analysen basierte Wartungsplanung für Eisenbahninfrastrukturen

Durchschnittliche jährliche Wartungs - und Instandhaltungskosten pro Kilometer Gleisstrecke betragen heutzutage für moderne Eisenbahnnetze ca. EUR (€) 50.000. Mögliche Kosteneinsparungen, erzielt durch eine zustandsorientierte Entscheidungsfindung, die in ein angemessenes Informations - und Entscheidungsunterstützungssystem eingefügt ist, werden auf Beträge zwischen bescheidenen 15% und optimistischen 55% eingeschätzt. In der vorliegenden Arbeit sind die wichtigsten Methoden des Zustandsmonitoring für Eisenbahnnetze, die derzeit weltweit angewandt werden, beschrieben. Außerdem ist das Analyseverfahren der zur Anwendung in Wartungs - und Instandhaltungsverwaltung gemessenen Daten dargestellt.

Schlüsselwörter:
Eisenbahninfrastruktur, Verwaltung, Wartung, Messungen des Gleiszustands

1. Introduction

The railway infrastructure is by far the most expensive item in the railway industry, generating maintenance and renewal (M&R) expenditures of monstrous proportions every year. For that reason, any reduction of these expenditures would significantly influence the overall efficiency in the management of Railway Infrastructure Elements' (RIE).

The process of determining whether, when, where and how to intervene and decide on an optimum allocation of resources, while minimizing the costs, is very complex because:

- different track sections tend to behave differently under the effects of load and environment;
- decision processes for M&R works are closely interrelated, both technically and economically;
- decision-making for M&R is based on a large quantity of technical and economic information, broad knowledge and, above all, on extensive experience.

Due to significant costs of the infrastructure, as explained above, it is paramount that the infrastructure be available for traffic as much as possible. At the same time, considering the increase in speed registered over past decades, the quality of infrastructure, primarily in terms of deviations from design values, must be maintained at the prescribed level at all times. In order to ensure adequate availability and quality of infrastructure, infrastructure managers must fully understand behavior of the infrastructure in order to grasp main causes of relevant problems and to accurately target M&R activities, and also to prevent repetitive interventions due to inappropriate actions causing costly reductions in availability. Ideally, the thorough understanding of infrastructure behavior would eventually lead to the ability of forecasting its behavior, thus preventing a great deal of failure events causing traffic disruptions. This would also enable timely planning of necessary actions and, hence, double cost-savings would be realized through an optimal and cost/effective organization of activities.

However, understanding the behavior of RIE is a highly complex task. The infrastructure consists of many varied elements and structures, of different age, type, and design, which are subjected to different volumes and types of detrimental influences (primarily resulting from railway traffic), and which react differently to different types of remedial activities performed to different quality standards. As a consequence of all this, each of these RIE exhibits different behavior under different circumstances, as can be seen via various condition parameters. Such a plethora of issues, aspects, combinations and interrelationships, makes it practically impossible for infrastructure managers to perform their difficult managerial tasks efficiently, irrespective of their knowledge and experience. This is why the following two requirements must always be met to ensure proper management of railway infrastructure assets:

a) appropriate means must be put in place to properly monitor and measure performance of infrastructure elements and
b) reliable methods, means and tools must be developed for assessing and forecasting condition of infrastructure elements, and for consequential M&R planning, as well as for optimization of resource allocation activities.

At the same time, these two requirements directly describe the conceptual framework of a properly designed Railway Infrastructure Asset Management System (RI-AMS).

2. Basic characteristics of the condition-based decision-making

All activities related to the RIE diagnostics, condition analysis, planning, and consequent realization of maintenance and/or renewal works, can be structured in the so-called condition-based maintenance chain, which is traditionally composed of the following main phases, Figure 1 [1]:

1. Monitoring and surveys: these are made either by survey vehicles or using other inspection systems that produce diagnostic data.
2. Analysis: necessary processing and storage of data for future use and visualization of diagnostic data.
3. Warning/alert generation: generation of information about defects, quality indexes, alerts, etc. to be subsequently used for planning M&R activities;
4. Planning: production of M&R activity plans for subsequent optimization.
5. Optimization: optimization of M&R plans to define and select the final plan, for which a detailed schedule of activities and resources must be prepared.
6. Scheduling and realization of activities: final phase oriented at resource allocation and implementation of M&R activities.
7. Management: final global control of overall performance of the maintenance process.

A wide range of diagnostic systems is available to support these three phases of the condition-based maintenance chain. Table 1 presents main categories of the systems currently available on the international market. Basic properties of the most significant systems, their use, and condition parameters they define, will be described in more detail in the next section. Diagnostic systems can be assembled and integrated on railway vehicles, allowing monitoring at low and high speeds. Depending on the needs and the budget of the railway operator, different types of configuration can be evaluated. All diagnostic systems can be assembled and integrated on:

- Dedicated vehicles, developed and produced by specialized companies, or supplied by railway operators themselves
- Commercial vehicles (locomotives, passenger trains, freight trains).

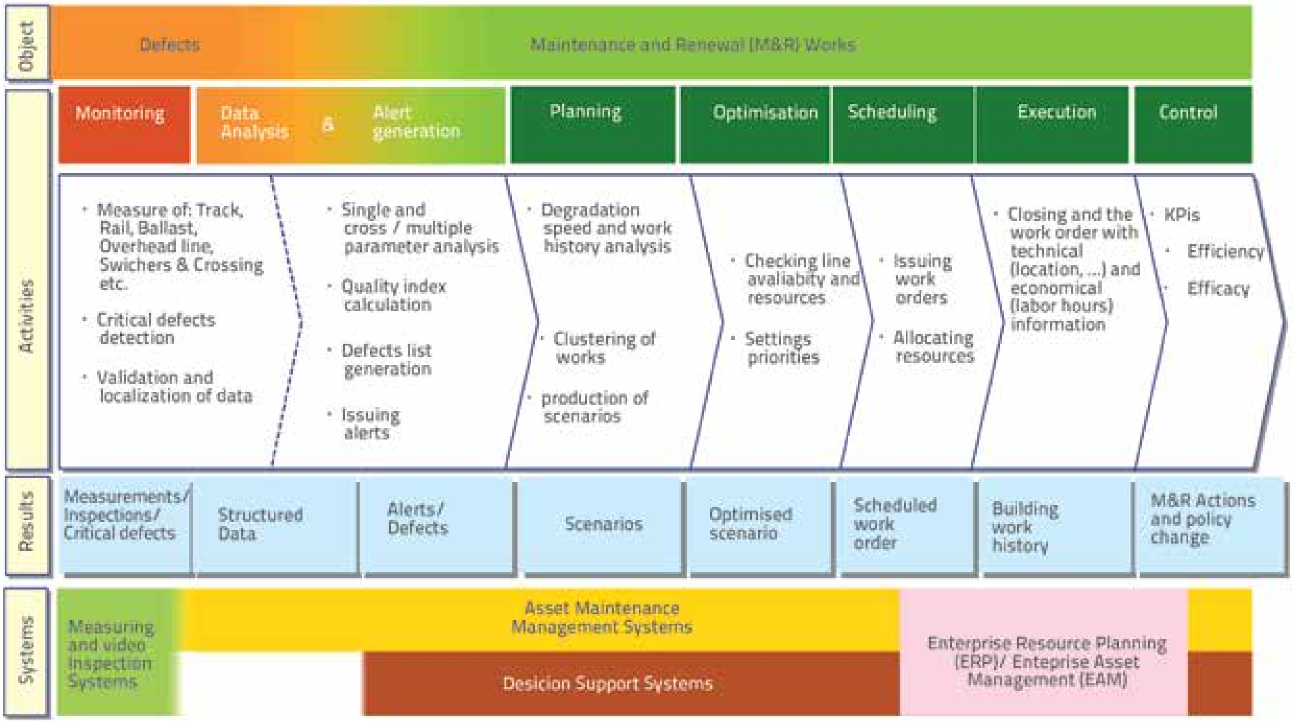

Figure 1. Condition-based maintenance chain

Table 1. Main categories of railway infrastructure monitoring systems

Category	Type of measurement
Track measurement	Track geometry Rail profile Rail corrugation Ballast profile
Overhead line measurement	Overhead line geometry Contact wire wear Pantograph interaction Arc detection Overhead line electric parameters
Vehicle dynamics measurement	Ride quality Body, bogie and axle boxes accelerations Wheel-rail Interaction forces Wheel-rail contact
"Vision" systems	Automatic rail surface defects detection Automatic overhead line defects detection
Video inspection	Railway section and surroundings Track surface Overhead line Platforms Way side
Other monitoring	Signaling Telecommunication quality Environmental temperature Tunnel ceiling status detection Railway infrastructure kinematic envelope/gauge Tunnel detection system Positioning system Monitoring of signaling systems Time radio-synchronization system

Also, all measuring systems are available for any type of track gauge and they can be operated:

- With operators on-board and real-time analysis (manned)
- Without operators on-board and with automatic data retrieval (unmanned).

2.1. Processing of measured data

Measurement data are normally retrieved in a so-called "raw format" (Figure 2). Thus, in majority of cases, they are inappropriate for M&R planning, which is particularly true for linear/spatial RIE. This is due to the fact that condition measurements for linear RIE are made by instruments that have their own measuring frequency, i.e. sampling-step, which are respectively either too high (frequency), or small (sampling step), which is appropriate for definition of local defects, i.e. local irregularities or exceedances.

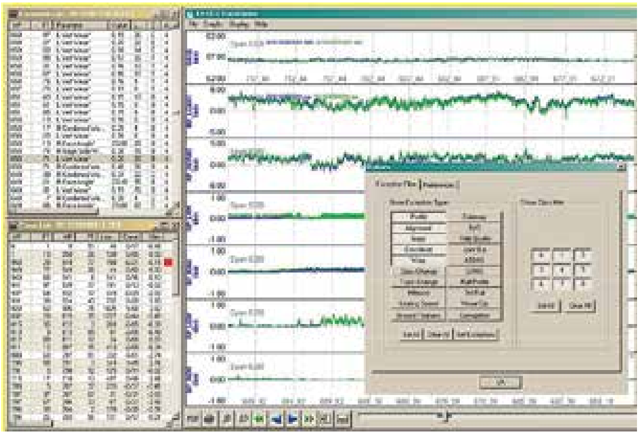

Figure 2. An example of track geometry raw measurement data

These exceedances are, most often, sent directly, in real-time, to responsible services within railway organizations so as to enable urgent interventions (this is in fact the only way in which these raw data are used without further processing). On the other hand, this also creates two serious problems related to the use of these data for other purposes, e.g. condition forecasting and M&R planning:

1. Due to high frequency, i.e. small sampling-step, as well as (in most cases) high travelling speed of measurement vehicles, the amount of data generated by these measurements can be enormous, which practically does not permit any kind of complex real-time analysis (e.g. in Italy, the amount of measurement data already exceeds 1 terabyte (TB) every two weeks! [2]
2. Condition forecasting and consistent M&R planning is based on the comparison of several consecutive measurements taken at the same location. As it is practically impossible to ensure that the measuring vehicles (i.e. measuring systems) will take measurements at identical locations every time, over several consecutive measurement runs, a certain shift/offset or location error always occurs between consecutive measurements, which does not enable their accurate matching for comparison purposes at the level of every single measurement point. Finally, when we consider that different measuring vehicles (i.e. different measuring systems installed on them) always have an inherent location error, that originates from inherent inaccuracy of the location systems, e.g. odometers, GPSs, etc., and depending on their level of sophistication (where older and less sophisticated systems have an accumulated error of several meters or even several dozens of meters!), it becomes automatically clear that direct comparison of consecutive measurements, at the raw-data level, is completely impossible, regardless of required repeatability values.

For the above reasons, in order to use the raw measurement data in further analyses, and especially for condition-forecasting for the sake of planning future M&R activities, it is necessary to process and convert these data into the so-called condition parameters. These parameters are further grouped and organized into quality indices the past behavior of which (as seen over several consecutive measurement runs) is then modeled and used for condition comparison with respect to some future time, and thus also for planning future M&R activities. There are several levels of condition parameters and all of them, except for those at the lowest level, are formed in the scope of the process called "segmentation", which represents the cornerstone for all subsequent analyses, modeling and planning activities [3, 4].

3. Railway infrastructure elements condition parameters and their measurement

3.1. Track geometry measurements

With the exception of drainage and substructure, track geometry deteriorates primarily due to the influence of dynamic loads exerted by vehicles. These dynamic loads cause deterioration of all track elements: rails (mostly due to fatigue, that is manifested through internal or surface defects), wooden sleepers (loosening of fasteners), concrete sleepers (wear at the area in contact with the ballast and fastenings, fatigue cracks), fastenings (cracking and failure due to fatigue), substructure (shaking and fatigue caused by high-frequency dynamic forces), as well as rapid deterioration of track geometry, both in the short-wave domain (0-3 m) and long-wave domain (3-150 m). More precisely, track with substandard geometry will:

- deteriorate faster when compared to good geometry tracks that retain/keep their good shape for a longer time-span
- exhibit more frequent failure of all track components, causing accidents, traffic disruptions and speed reductions

Therefore, the track geometry exerts an influence on all track components and their service lives. For that reason, keeping good control of track quality brings increased rail operation revenues and this through reductions in the number of accidents, traffic disruptions and slow orders (speed reductions) as well through M&R cost savings [5].

Measuring systems for monitoring various track geometry parameters have been available for several decades now, and today the fourth or fifth generation of such devices is used. They mainly make use of innovative techniques based on no-contact opto-electronic technologies, and no-contact measurement systems based on inertial techniques, instead of traditional old-fashioned "contact" track measuring systems, involving the use of mechanical devices in contact with rails, which were therefore prone to wear and gradual loss of accuracy, as well as frequent damages due to dynamic impacts and vibrations. In recent years, track geometry measurements have been standardized in the scope of the CEN Committee (*European Committee for Standardization*). The TC 256 (Working Group 28) prepared in 2008 the European standard EN 13848 "*Railway applications - Track - Track Geometry quality*". This standard covers several aspects concerning characterization of track geometry and measurement devices.

The following parameters are covered by this standard:

- Track gauge
- Longitudinal level
- Alignment
- Cross Level
- Twist

Table 2. Track geometry measuring principles and techniques

Measuring principle and technique / Track geometry parameters	Principle			Technique	
	Direct	Inertial	Chord- based	Contact	No-contact
Gauge	✓			✓	✓
Longitudinal Level		✓	✓	✓	✓
Alignment		✓	✓	✓	✓
Cross Level		✓			
Twist	✓	✓		✓	✓

A measurement method that includes both measuring principles and allowable techniques has been adopted for each parameter. Table 2 presents the principles and techniques available so far for each of the parameters.

"Contact" systems are inadequate for high-speed measurements, and they also require constant monitoring, calibration, repair, or replacement of measuring wheels, due to their wear and tear as a direct consequence of the contact with rails. Calibration is required at every survey, and it also quite often needed even during the surveys. Accuracy of measurements is also influenced by the wear of measuring wheels because wheel irregularities can produce unrealistic/false defects, thus frequent maintenance is required. Also, when the measurement vehicle passes over switches or level crossings, it is sometimes necessary to lift up measuring wheels to avoid damage. Some measurements might also be lost, i.e. measurements can not be made, at track sections characterized by excessive rail wear.

The performance of measuring systems based on inertial principle is strictly dependent on speed. In general, inertial systems often experience problems when measuring at low speeds and with rapid accelerations / decelerations of measuring vehicles (for example at train stations or at switches), which can cause either a loss of measurements or unrealistic/false measurements (defects). Moreover, processing algorithms involve some complex filters requiring very high frequencies, i.e. a very small and highly accurate measurement step, which can not easily be achieved [6, 7].

Laser no-contact measuring systems do not suffer from these limitations, and their particular advantage is that they can measure:

- At very high speeds (because no parts are in contact with rails or any other objects, and there are no moving parts),
- At very low speed (all the way down to 0 km/h),
- All parameters at the same speed,
- Without effects/consequences produced by (very) rapid changes of the dynamic behavior of the coach (accelerations/decelerations), unlike inertial systems,
- Without mechanical elements subject to wear, i.e. high MTBF (Mean Time Between Failures), thus no need for frequent re-calibration, unlike contact systems,
- Both rail-profile and track-geometry at the same time, and in an integrated way.

Modern track geometry and rail profile measuring systems are fully integrated, allowing for track geometry parameters to be extracted from the rail profile measurements (Figure 3).

Figure 3. Rail profile and track geometry measurement devices

Measurements are performed at every 25 cm at any vehicle-speed using lasers, special sensors and cameras. First, a specialized software analysis is conducted to extract gauge values from the rail profile measurements. Furthermore, the rail profile and the gauge point serve as the basis for detection of the longitudinal level and alignment of both rails adopting the "chord/versine" technique.

An inertial system, consisting mainly of inclinometer and rate sensors, is used for the measurement of cant, based on which twist values are calculated. Rail wear is calculated by subtracting the measured rail profile from the nominal (as new) one (obtained from the database for the known rail types), while the right and left rail profiles are used to calculate the "equivalent conicity" (and the contact gauge angle).

Integrated measurements of track geometry and rail profile enable cross-correlation type of analyses and correlation of measured values in the track, especially through the use of RI-AMS systems, allowing detection of root causes of various problems and defects.

Figure 4. Specialized measuring vehicles and portable/hand-held measuring systems [8]

3.2. Rail corrugation measuring

Rail corrugation is known to significantly increase dynamic force values, which can considerably affect the long-wave track geometry. These two things together can severely reduce the service life of all track components. Rail corrugation can cause both surface and internal defects in rails, cracking of concrete sleepers, loosening of fastenings on timber sleepers, and ballast crushing. This is due to the following two reasons:

- higher dynamic forces, and
- repeated tamping initiated by recurring long-wave track geometry problems, as well as very dangerous disturbance to the substructure.

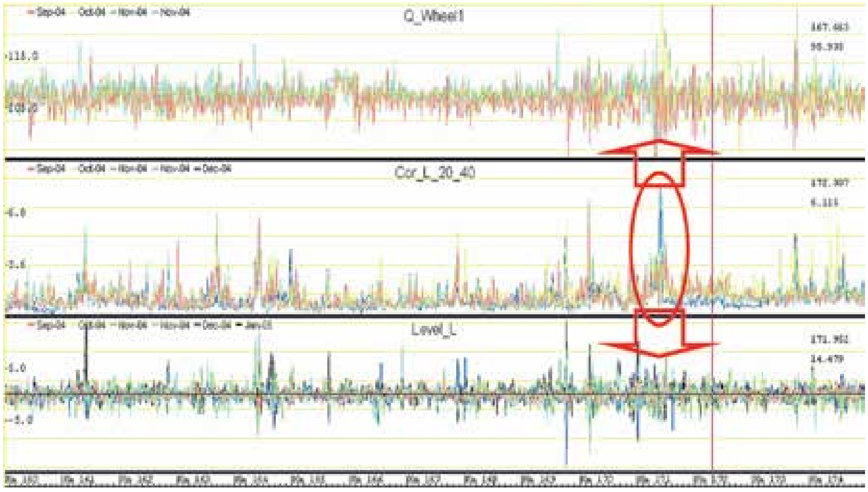

Figure 5. Corrugation consequences

The causal relationship between the corrugation (as the root cause), dynamic forces, and track geometry (as consequences) can best be seen from the corresponding measurements such as those conducted in Italy and represented within the RI-AMS system, cf. Figure 5. In fact, several such locations can be noticed in Figure 5 and, if displayed in an obvious and user-friendly manner, as in RI-AMS, it does not take a lot of expertise to notice the causalities.

However, the following finding is perhaps the most striking: if, for instance, we take a closer look at the marked location (Figure 6), and if we calculate the corrugation progress over time and the consequences of this corrugation (dynamic forces and track vertical level), then it can be established that they follow an identical pattern. Then if we include the visualisation of work history (Figure 7) into our analysis, we can see already at the first glance that this location has been consistently and frequently tamped (on several occasions or, more precisely, four times), and yet the track geometry problem was recurring (and, in fact, the problem was worsening).

It was then established that the problem is due to a completely different albeit highly significant reason: the existence and worsening of rail corrugation to which no attention had previously been paid and hence, the problem was not eliminated (by rail grinding). Therefore, instead of the repeated tamping, this section should have been treated by rail

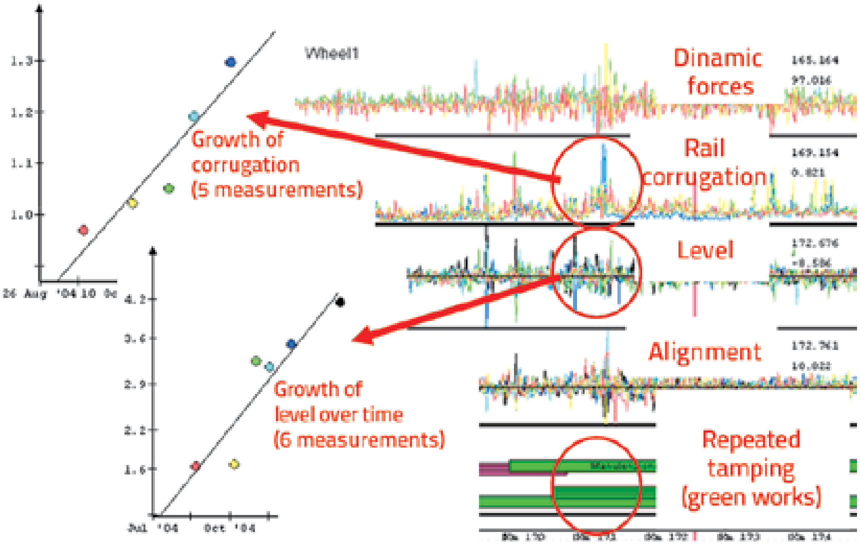

Figure 6. Corresponding time-progression of Corrugation and Track Geometry (Vertical Level) and repeated (unnecessary) Tamping remedying the symptom instead of the root-cause

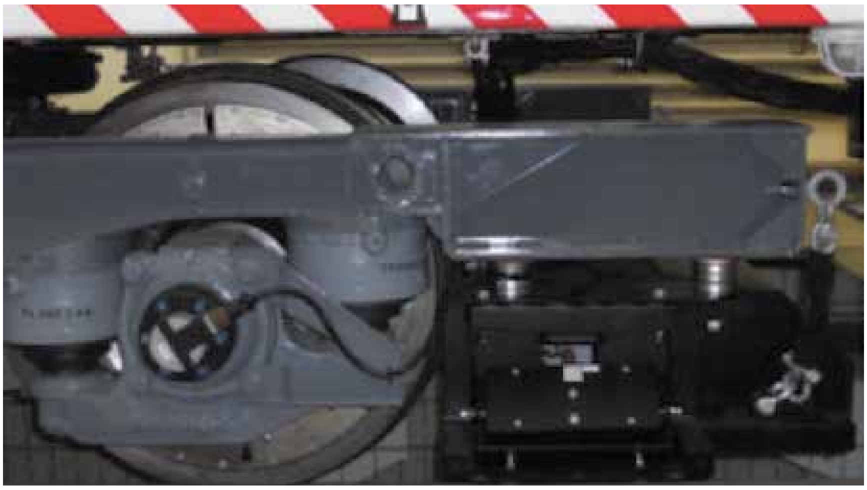

Figure 7. Rail Corrugation Measuring System Setup

grinding, and only then by tamping. In this way, the behavior of this section would have been much more stable both as to track geometry and rail corrugation, while the tamping effects would have been more durable. In this case, it is regrettable that no information on the existence and increase of surface and internal rail damage was available. If this information were available, it would most probably additionally back the results of this analysis and confirm the conclusion that multiple harmful occurrences on this locations were in fact caused by rail corrugation. The most harmful occurrence, which was unfortunately the least visible and provable, is an increase in fatigue at all track components on this location, caused by an increase in dynamic forces, which has severely shortened their service life, which ultimately resulted in a considerable increase of maintenance and renewal costs.

The fact that an increasing attention is currently being paid to the rail corrugation issue, has prompted development of a number of highly-accurate corrugation measurement systems (Figure 7). This has allowed railway authorities to measure and monitor the existence and build-up of corrugation and, with the help of powerful RI-AMS systems, to correlate this information with other data in order to gather significant, albeit often hidden, correlations and contingencies, and to finally identify true causes of problems, and devise the most adequate remedial activities.

A track corrugation measuring system is based on the laser optical no-contact technology, which relies on high-speed digital cameras and laser sensors. A typical sampling distance is 5 mm and the measuring speed is 0 ÷ 120 km/h, while the measured parameters and their respective accuracies are given in Table 3 below.

Table 3. Typical condition parameters of the rail corrugation measuring system and their respective accuracies

Parameter: rail corrugation	Accuracy
Short waves (30 mm – 100 mm)	± 20 μm
Medium waves (100 mm – 300 mm)	± 50 μm
Long waves (300 mm – 1000 mm)	± 200 μm

3.3. Track surface inspection systems with automatic detection of defects

This is one of the most recent areas in the sphere of RIE condition monitoring, which is why very few systems and suppliers are available on the market. The track Surface Inspection using "Vision" Technologies" is based on the following 3 approaches:

- Track Surface and Right of Way Inspection (Figures 8 - 12)
- Rail Components (e.g. joints, joint gap) and Rail Surface (e.g. head checks) Inspection (13-15). (head checks are small cracks on the rail head surface at the contact with the wheel, and they always develop in the direction of dominant traffic and can cause serious rail fractures with catastrophic consequences, as in case of the Hatfield accident in the UK, in 2000)
- Track Surface Measurements (Figure 16).

The track Surface and Right of Way Inspection provides innovative functions for real-time video monitoring of track condition, and for automatic recognition of resulting defects. Traditional video inspection of the rail surface involves participation of specialized personnel who analyze visually all images that have been recorded. This activity is clearly time consuming and potentially hazardous because the results are strictly dependent on the ability of the viewer to detect possible anomalies and report critical situations. On the other hand, Imaging Systems for defect detection automate the defect recognition and thus speed up the inspection process by reducing the image analysis time and increasing reliability of the detection process (Figure 8), [9].

The Track Surface and Right of Way Inspection can be used for:

- Detection of sleeper types & moving sleepers
- Detection of the condition and type of rail fastenings, including fastenings in (unwanted) contact with wheel flanges
- Rail surface defects
- Black Holes
  - Burnings
  - Rail Break
  - Crushed Head
  - Cracks (thickness > 0.7 mm)
- Base plate condition in absence of ballast and pincers position
- Joint gap measurement estimations & head checks
- Checks of ballast irregularities, presence of vegetation, structural condition of magnets, pass-through, axle counters, AFI and ETCS balises, etc.
- Detailed analysis
  - Markings detection
  - Missing bolts
  - Released shoulder plate
  - Misfit rail pads
  - Distance/position of clammers with respect to the sleepers/fastenings

The Track Surface and Right of Way Inspection is based on the no-contact optical technology using high-speed and high-resolution cameras for track image acquisition. Enhanced vision algorithms identify and classify defects according to their properties and/or their position in the track. The system extracts rail images in real-time, and identifies their position using odometer. In the scope of post-processing, each image is analyzed to automatically identify the defects according to their size, severity, position, etc. (Figures 8 to 12).

The *Rail Surface & Components Inspection* consists of high-speed high-resolution cameras allowing automatic detection and highly accurate inspection and measurement of rail components, joint/weld gaps and rail surface, e.g. head-checks (their length, width, angle and clustering), all this at very high speeds of up to 250 km/h.

The size/width of rail joints and welds is very important because it directly influences the rise of dynamic forces, which in turn decisively influence the life of all track components beneath and in the vicinity.

Figure 8. Track surface and right of way inspection [10]

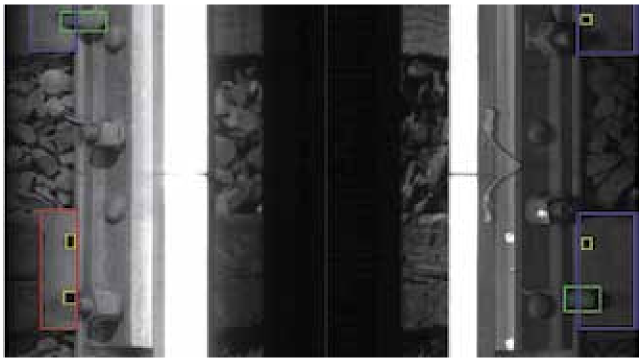

Figure 9. Track surface inspection system – defect detection (missing spikes) [10]

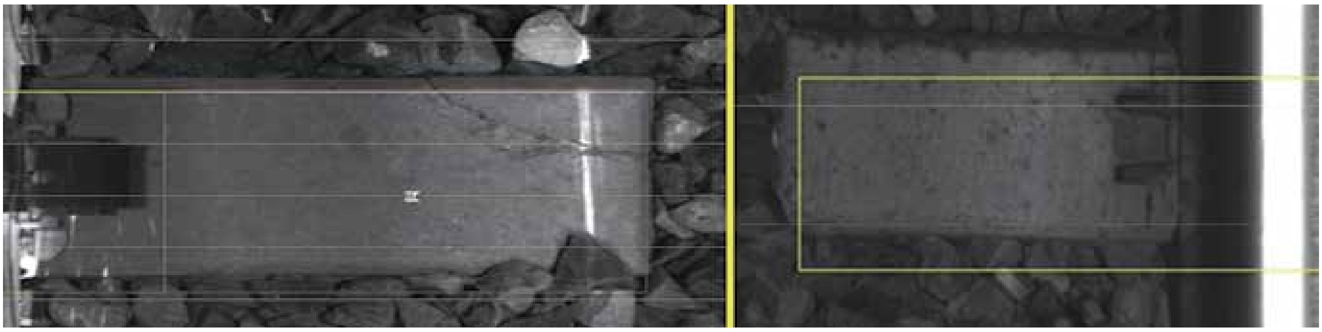

Figure 10. Track surface inspection system – cracked sleeper (left), missing fastener (right) [10]

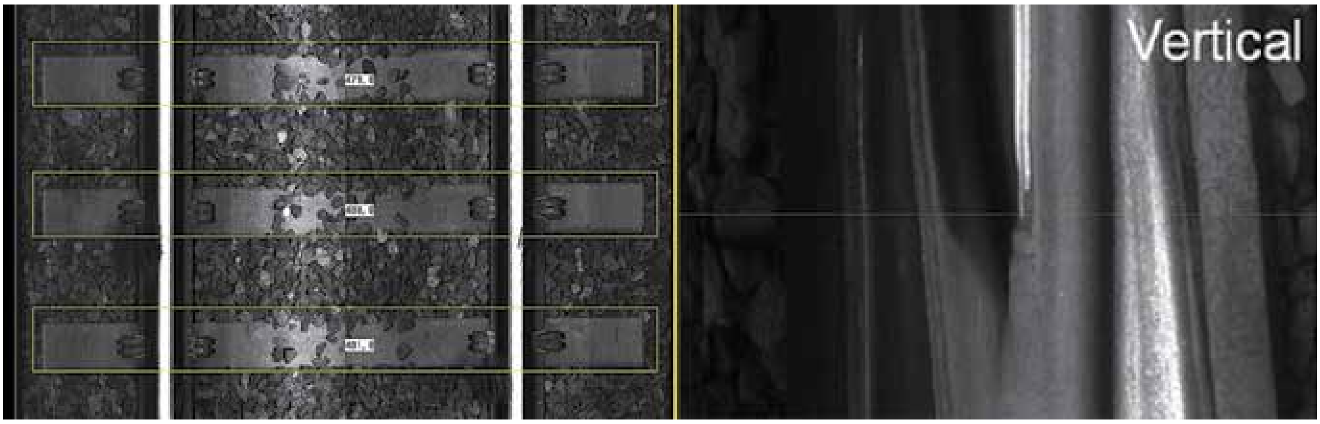

Figure 12. Track surface inspection system – checking sleepers & switches validation [10]

Figure 11. Track surface inspection system – mud & moving sleepers detection

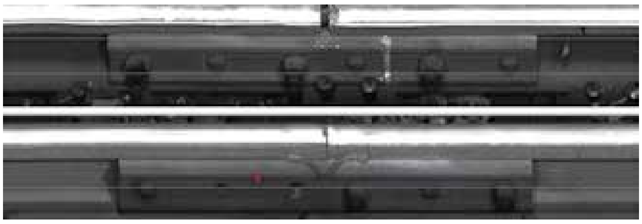

Figure 13. Rail surface & components Inspection – rail batter & missing bolts [11]

Rail head-checking (rolling contact fatigue – RCF, or gauge corner cracking - GCC defects) in turn has become an issue of an outmost importance for railways World-wide in the recent years due to their sudden and often worryingly drastic rise observed in the recent years. RCF defects like head-checks, if left unattended could develop very quickly and turn into rail breaks of often fatal consequences, as could have been seen from the tragic accident at Hatfield, Hertfordshire, UK, on October 17, 2000, when a Great North Eastern Railway Intercity train bound for Leeds, traveling at over 115 mph (185 km/h), suddenly derailed south of Hatfield station and four people were killed and a further seventy injured. When a preliminary investigation found that a rail had fragmented

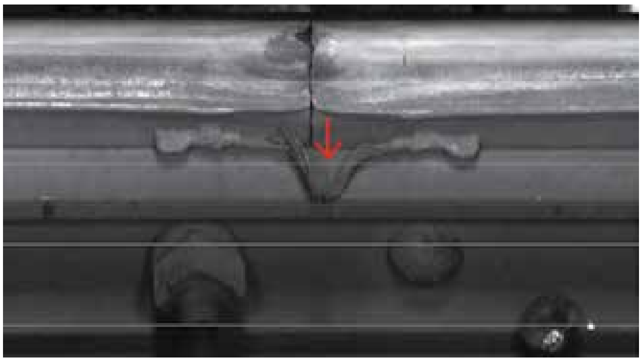

Figure 14. Rail surface & components Inspection – cracked joint bar [11]

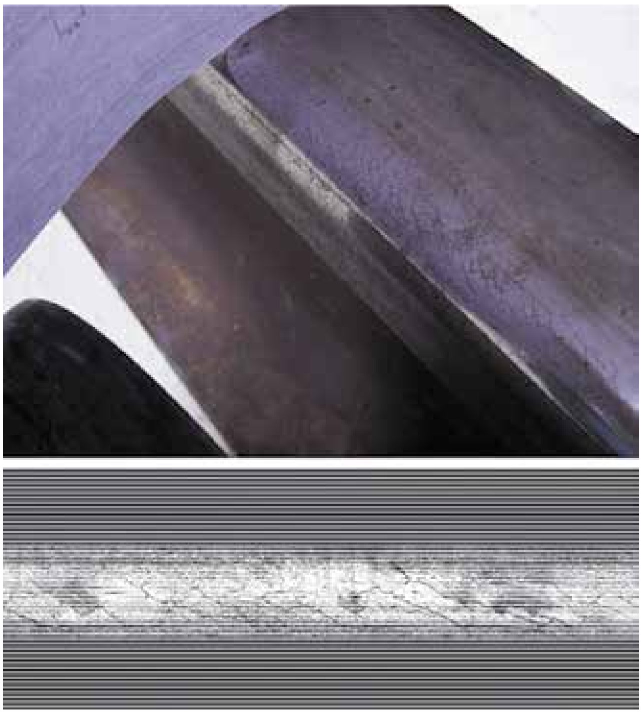

Figure 15. Rail surface & components Inspection – head checks defect (above – real-life rail, as seen by a human eye; below – the same rail as seen by the measurement system)

while the train had passed over it, and that the likely cause was "gauge corner cracking" (microscopic cracks in the rails), it led to temporary speed restrictions being imposed on huge lengths of Britain's railways.

Track Surface Measurements are often made using area scan cameras in association with a set of laser blades to accurately measure the position of various track objects, in order to conduct the following verifications requiring high intensity processing:

- Inspection of Switches & Crossings components
- Detection of ballast irregularities
- Vegetation check
- Distance measurement between different rail fastening components
- Checking of the structural condition of magnets, pass-through, axle counters, AFI, ETCS balises.

In order to perform required detections and measurements, the system takes a laser-based 3D scan of the entire track beneath and all objects present in it, representing it as a 3D model, Figure 16. A specially developed software allows viewing of these images and their playing in a video format of the user's convenience. However, a truly intelligent analysis comes after visualization. In fact, the system does not require manual 2D or 3D visualization at all, and it undertakes all detections, identifications, measurements and all other processing actions automatically, using highly-sophisticated methods like pattern-recognition techniques and neural-networks algorithms, [12].

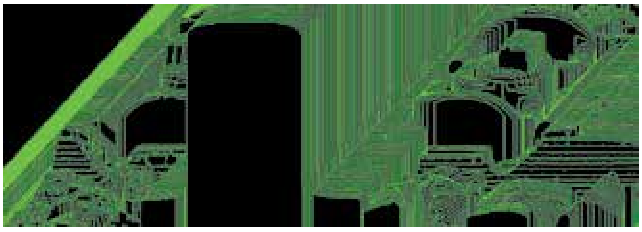

Figure 16. Track surface measurements – 3D interpretation, measurements & detection

3.4. Overhead line and contact wire measurements

The overhead line M&R works are carried out on-site usually during the traffic-free hours by using extensive manpower and expensive plants. So, a precise picture of the overhead line geometry status and the contact wire wear are very important to the railway infrastructure maintainer to optimize the works on the line. In contrast to manual wire-wear measurements using gauge or caliper, which are inefficient and error-prone, today's overhead-line measuring systems based on CCD cameras and laser technologies allow accurate no-contact measurements of both overhead line geometry and contact wire wear at low and high speeds [13].

The data acquired by overhead line measuring systems allow calculation and storage of several parameters concerning overhead line conditions, like stagger, height, gradient of the contact wire, wire thickness, wire quality indexes, etc. Parameters regarding the degree of wire wear and wear evolution rates are fundamental for monitoring problematic locations along the wire that might lead to wire breakage in the short term. Moreover, the historical analysis of the wire wear data can be used to formulate optimized and objective wire replacement plans based on deterioration of the contact wire quality index (IQF), as illustrated in Figure 18, based on the contact wire measurements, Figure 17.

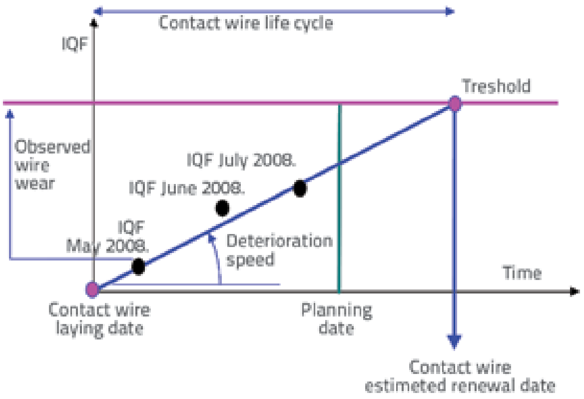

Figure 17. Contact wire quality index over time

When both overhead line and track geometry data are available (which is unfortunately quite rarely the case), the cross-correlation of different parameters can be carried out in order to identify the real cause(s) of overheard line defects, especially the situations where the damage is primarily due to the poor track geometry condition, rather than to the cumulative effect of the different train types that travelled along the track.

Figure 18. Overhead line measurement system

Modern no-contact OHL measuring systems (Figure 18) are usually used to perform integrated measurements of both the OHL geometry (height & stagger) and the contact wire wear (accuracy 0.1 mm), at speeds ranging from 0 to 300 km/h, both in static and dynamic conditions. All OHL geometrical parameters are referenced to the track centerline, by adequate processing/compensation with respect to:

- transverse movement of the measuring section in curves
- The rolling and the vertical movement of the vehicle.

4. Conclusions

The condition-based approach implies that the maintenance and renewal decisions are made based on the real railway infrastructure elements' condition, and the manner in which this condition is changing (over time, or even better, with respect to the manner and extent of exploitation), which gives the railway infrastructure elements' "behavior", and not based on predefined maintenance and renewal cycles. Obviously, the condition-based approach also implies that the condition, i.e. the behavior of railway infrastructure elements can be measured in all of its aspects, and properly understand via such measurements.

At the same time, the mission of the "condition-based" approach is to shift the existing maintenance and renewal management concept from today's predominantly corrective, prescriptive and cycle-based approach to the tomorrow's approach, which is preventive, predictive and above all condition-based.

This shift can be made by increasing the amount of condition-monitoring and by ensuring much better understanding of the asset condition (from as many aspects as possible) and its change in time (which yields the asset behavior). Then, using the advanced Railway Infrastructure Asset Management Systems - RI-AMS, huge quantities of condition data can efficiently be processed, which is a very important advancement in modeling behavior of rail infrastructure assets, paving the way towards predicting their behavior. This finally allows reliable forecasting of the asset's behavior and hence also of the moment when this behavior would exceed allowable limits (thresholds), thus enabling a predictive-preventive maintenance. With this ability, the extent of planned predictive-preventive maintenance is increased at the expense of corrective maintenance, and that is precisely where enormous cost-savings can be made.

This can be considered as especially important in case of railways operated in the Southern and Eastern Europe, as the quality of their infrastructure is often below desired, which means that they will certainly require significant repairs and reconstructions in the years to come. Such objective condition-monitoring, and above all condition-analysis methods and systems, would thus be highly beneficial, as they could effectively prioritize necessary activities and yield optimum plans, both in short and long term.

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