Predictive Maintenance of Tracks to Ensure Availability and Reliability of Critical Railway Infrastructures

U Martin*, S Bahamon-Blanco

Institute of Railway and Transportation Engineering, University of Stuttgart, Pfaffenwaldring 7, 70569 Stuttgart, Germany.

*Corresponding author's email address: ullrich.martin@ievvwi.uni-stuttgart.de

Abstract. One important task to guarantee the proper operation of trains are the maintenance plans of the railway infrastructure. The railway infrastructure includes different elements such as stations, telecommunications, electrification, signaling of the lines, and the tracks. The effective and timely maintenance plans of these elements help to provide high performance, safety, and additional benefits to the railway sector. In this research paper, the importance of railway maintenance plans is explained by taking into account the economic effects of the Rastatt Incident, the development of the German rail network, conventional and alternative diagnostic systems for collecting different track geometry parameters, and different ways to determine suitable parameters. At the end of the paper there is a comparison of how maintenance was previously done, how it is currently carried out, and how it expected to be in the future.

1. Introduction

Maintenance plans have been implemented for many years, and the methods used for maintenance plans have become more advanced and more precise over time, to the point that it is now possible to carry out so-called "predictive maintenance." Predictive maintenance is a practice that allows for the identification of irregularities on the track before they reach a critical state. It is important to implement the use of predictive maintenance on the elements of the infrastructure, for example in the track to ensure the availability and reliability of critical railway infrastructures.

1.1. Objectives

Initially, the practice of predictive maintenance was conducted to maintain a high level of performance and due to safety reasons. But beyond that, the infrastructure should be in a good condition, providing a continuous service to generate profit in different sectors. Additionally, predictive maintenance is implemented to avoid critical and high-cost maintenance because a critical interruption of the operation affects the capacity of the network, travel time, and causes economic damages as clearly showed in the Rastatt Incident.

1.2. Rastatt Incident: Economic damage

The good working condition of the railway infrastructure helps to provide an efficient operation and the economic profit of the public transport, logistics, and manufacturing sectors. On 12 August 2017[1], the rail infrastructure tunnel near the German town of Rastatt in the Rhine Valley collapsed when an inspected, deliberately-iced surface broke into one of two new tunnels [2]. This event caused a seven-week interruption to a part of one of the busiest freight railway routes in the EU: the Karlsruhe-Basel line. The Karlsruhe-Basel line is a part of the Rhine-Alpine Corridor and connects the ports of Rotterdam, Hamburg, and Antwerp to Switzerland and Italy. This incident, known as the "Rastatt Incident," disrupted the rail freight-based logistic chains throughout Europe. The total economic damage due to this incident was calculated to be 2.048 billion euros according to the European Rail Freight Association [3].

Figures 1 and 2 show the damage generated by the collapse of the tunnel, it is clearly seen that the structure of the railway fails, affecting many elements such as the ballast, sleepers and rails.

Figure 1. Deformation of the railways [4]. **Figure 2.** Aerial picture of the incident [4].

Even when some sources say that the collapse was due to "bad luck" and that "the Deutsche Bahn's network planners had never expected such an event" [2], there are measurement systems, such as piezometers or inclinometers that could be used to find some irregularities and suggest an intervention at a very early state. The acquisition and installation of those instruments can be expensive, but nothing compared with the high costs shown in Figure 3.

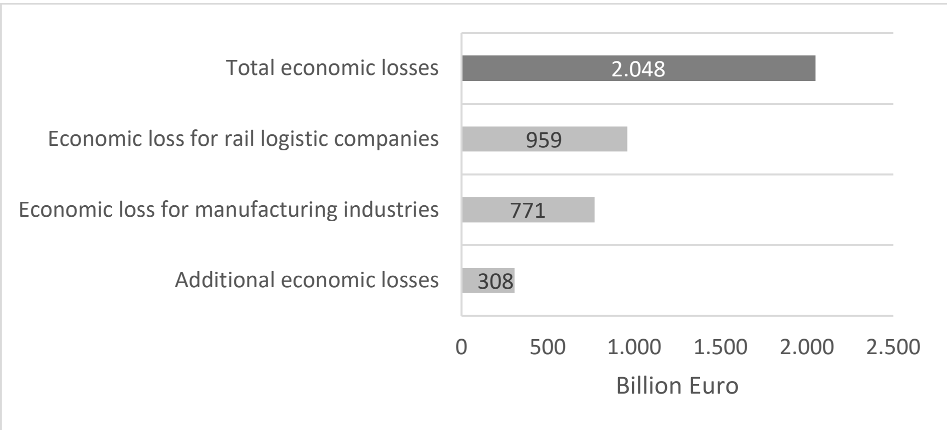


Figure 3. Total economic losses associated with the Rastatt Incident [1].

1.3. Railway network maintenance

The development of the railways as a mass transport system caused the extension of the railway networks within the whole of Germany. The first public railway line in Germany started with 6 km in 1835 in Nuremberg, the first long-distance railway with a total of 120 km was built in 1839, and by the time of the founding of the Deutsche Reichsbahn Company in 1920 there were more than 53,000 km of railway lines in the German network.

Figure 4 shows that initially there was a linear increase in the extension of the network, and that since 1915 it has been decreasing. One of the reasons is because the current territory of Germany is smaller than the territory of the German Reich (1919-1933) and also smaller than it was before the Second World War (1942-1945).

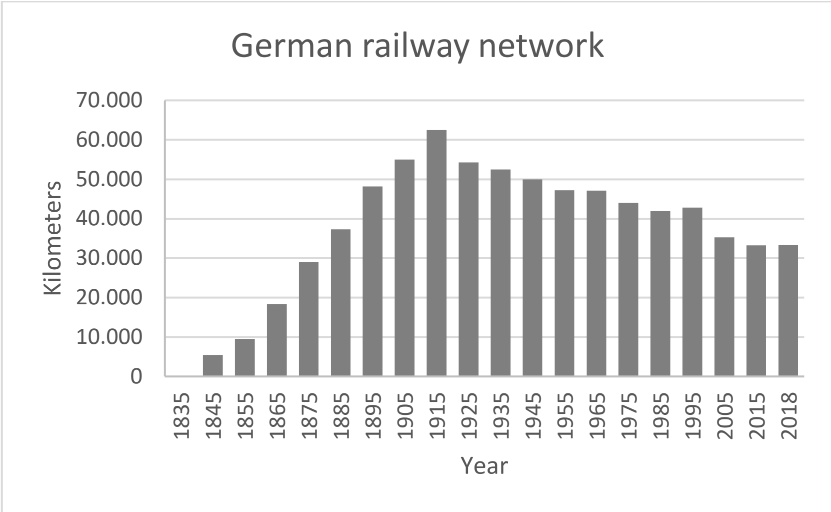


Figure 4. Length of the German railway network (1835-2018) [5].

Between 1994 and 2001, there was a decrease in the number of staff. Since the acquisition of the subsidiaries Schenker AG in 2002 and Arriva in 2010 (neither of which are responsible for the railway network), the number of staff members has slowly increased [6] as it is shown in Figure 5.

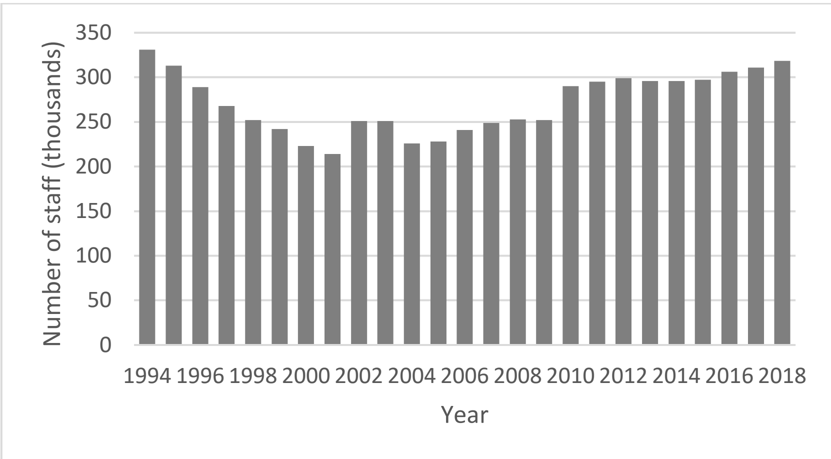


Figure 5. Number of Deutsche Bahn staff (1994-2018) [6] [7].

In the past, the guarantee for the good condition of the track was the responsibility of experienced workers at the railway network who analyzed the defects on the rails and determined the locations of problems that needed to be fixed. The workers were assigned specific track sections that were checked every day. Their work was experience-based and often focused on absolute values, such as the position of the fissures in the rails or the depth of the settlements.

The development of devices such as signaling control at the beginning of the 20th century helped in the detection of some rail problems. For example, the instruments used to measure the current of the points machines to move the switchblades could detect a failure in the continuity of the rails when the value of the current was out of a certain range. These detected failures are not necessarily critical, but being detected in this way can lead to early maintenance intervention in a controlled manner.

The measured values of the current in the example described above also depend on external factors such as temperature and humidity, and the acceptable ranges can be different depending on the season of the year: for that reason they are known as external factors. These external factors define the conditions and limits to identify problems in the rails. For example, in spring certain values indicate the existence of irregularities in the rail, but in winter the values must be higher to indicate the same irregularities. In addition, the measurement record of the internal parameters over a certain period of time period can indicate changes in the state of the rail in terms of the relative values.

In the past, maintenance plans were often focused on measuring absolute values, but with the concept of predictive maintenance, the focus is more on measuring relative values with consideration of external factors.

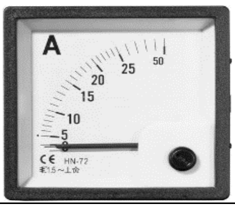
2. Predictive Maintenance on the Track

The term "predictive maintenance" refers to the analysis of certain parameters that can be used to suggest an efficient maintenance plan. Predictive maintenance has been applied for a long time, initially using basic devices that are part of the conventional diagnostic system, and nowadays with more specialized instruments that belongs to the alternative diagnostic system.

Additionally external data from official sources can be used (e.g. temperature or number of train axles passed). This data is collected by both diagnostic systems and contains historical information that should be selected according to the objectives of the measuring.

2.1. Conventional diagnostic systems

Conventional diagnostic systems have been used throughout history to measure important parameters related to the track geometry such as the rail gauge, alignment, and rail profile. When it is determined that the measured values are out of a certain range, a predictive maintenance plan can be made to prevent possible incidents such as what occurred in Rastatt. Table 1 shows some instruments used by the conventional diagnostic system.

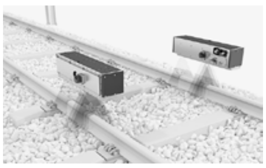
Instrument	Description
	**Ammeter:** It is part of the instruments used by electro-mechanical signaling controls. It measures the current of points machines, and if there is a problem with the switchblades, the current oscillates with values that indicate the existence of a failure.
	**Rail gauge:** This device measures the distance between the inner sides of the heads of the two rails, when a load is applied to them. If this distance varies more than expected it may be due to weak gauges, clusters of weak ties and broken fasteners that affect the movement of trains.

	**Alignment gauge:** This instrument measures the deviations of the rail vertically and horizontally, with respect to the alignment of the railway design. These deviations serve to suggest local maintenance, where measurements are very close to critical ranges and are also used to determine speed limits.
	**Cross level transfer gauge:** This instrument measures the elevation difference between the upper surfaces of the two rails at any point along the train track. Those measurements indicates the super-elevation which prevents centrifugal forces from diverting the train from the track. If the measurements are low, the speed of the trains should be reduce to avoid derailment.
	**Rail profile gauge:** This instrument uses a laser to determine the cross section of the rails. It is done to measure the wear of the rails, and suggest a repair or replacement of defective rails.
	**Track testing vehicle:** This vehicle can measure several geometrical track parameters: for example, the sharpness of a curve using the degree of curvature. The monitoring of the radius of the curves along a route is important because high speeds generate strong centrifugal forces in sharp curves that can cause derailments.

Table 1. Conventional diagnostic systems [8].

2.2. Alternative diagnostic systems

New, alternative diagnostic systems have been created to indirectly analyze different track parameters. Most of its instruments measure accelerations, wavelengths, angles, or electrical resistances using mathematical correlations to determine and locate deformations in the geometry of the track.

Instrument	Description
	**Laser measurement:** Laser measurements generates a signal of high and low range waves reflected in the rail and with the help of complex calculations the signal is processed to detect rail corrugations.
	**Camera:** Cameras are installed in trains to collect images of the track. These images are processed as matrices in complex algorithms as convolutional neural networks in order to detect specific failures in the surface of the rails. This is similar to facial recognition technology used in security systems.

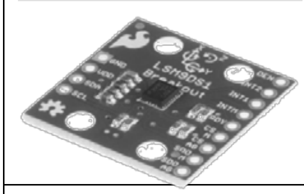
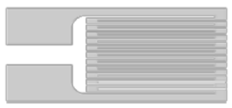
	**Accelerometer:** If these devices are installed in the axle box of a train, the measured accelerations can be used in complex statistical analysis, to train and create artificial intelligence models able to detect different types of failures in the rail.
	**Gyroscope:** A gyroscope is a device which determines orientation. As well as the accelerations, the measurement of the orientation of the vehicle are useful to train and create artificial intelligence models able to detect failures in the rail.
	**Strain gauge:** The strain gauge is a sensor that can be fixed at on rail and whose resistance changes when a force is applied on it. The measured resistances are able to calculate the amplitude of the force applied (pressure or tension) by means of correlations. This data can be used in a complex process to determine the existence of rail failures.

Table 2. Alternative diagnostic systems [9] [10].

2.3. External Data

External data is available in official sources, for example the datasets of the Deutsche Bahn AG [11], which provides historical information about the net, the tunnels, the trains and the routes. Even when this information doesn't have a current measuring of a specific geometry track parameter, it helps to complement the analysis of the quality of the track.

3. Suitable parameters

The track geometry parameters already described can be classified as internal parameters because they belong to the railway track conditions.

This information is used in different approaches, for example in the Building Information Modeling (BIM), updating the databases of the condition of different elements of the railway. Additionally, this information is used in artificial intelligence (AI) models, which use complex algorithms and intelligent evaluations to determine which of the parameters are more relevant for creating machine learning models capable of detecting failures, as also explained in detail by Bahamon-Blanco in [12] for instance.

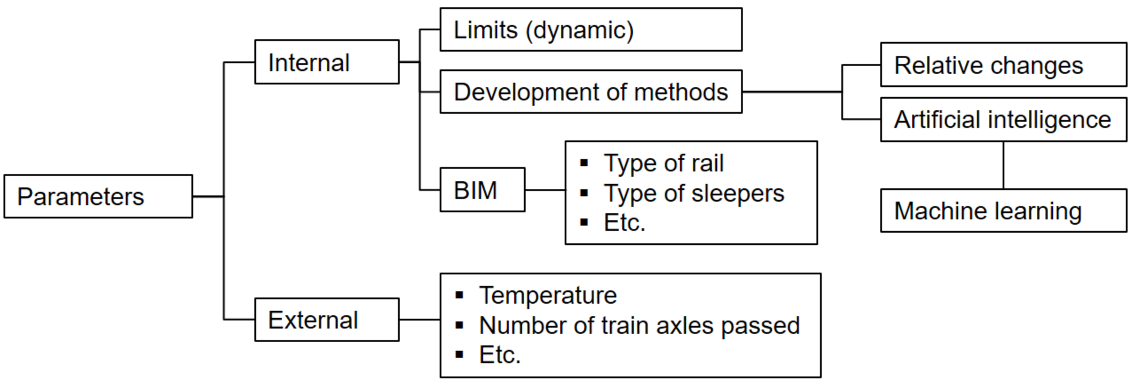


Figure 6. Different ways to determine the suitable parameters.

When working with artificial intelligence, there are different tools used to process the data. One of the examples to evaluate the parameters is the diagnostic feature designer. This tool can rank a list of features according to the ANOVA score, which analyzes the variance of the dataset [13]. This rank indicates the most suitable parameters that can be used to train machine learning models that are able to automatically detect failures.

4. Conclusions

Predictive maintenance is a practice that has been developing along with the technology and the needs of the railway sector to provide for the demanded high standards of the railway industry.

4.1. Pros and cons of the data collection methods

As described in this paper, there are conventional and alternative diagnostic systems used to collect data and also external data from official sources.

External data can be used to analyze the historical changes of a certain parameter, however the current state of the infrastructure depends of the diagnostic systems.

Conventional data is relatively inexpensive to collect and is easy to interpret, but it is focused on absolute values and the information is not continuous.

Alternative data includes a permanent updated state of the track, but it is expensive to collect and the analysis of the data is complex.

4.2. Results

In the past, maintenance was conducted by experts and by using different instruments. The development of new technologies will allow for standard trains to collect measurements for maintenance on their own during normal operation.

- Past: There was a need for experienced workers who determined the locations of problems that needed to be fixed. The workers were assigned specific track sections that were checked every day.

- Present: Using different methods and devices on special vehicles, it is possible to find important parameters (developed from experience and scientific investigations) that are used to determine the suitability of the track.

- Future: In addition to the special vehicles used to measure track geometry, standard vehicles will also be able to continuously measure the state of the track by incorporating sensors that provide real-time information and detect failures in their first stages during normal operation.

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References

[1] ERFA, NEE, UIRR 2018: Study finds Rastatt incident to have caused losses of more than €2 billion
[2] Fender K; Railengineer 2017: Why Europe’s busiest railway collapsed at Rastatt [09 Aug 2019];

Available from: https://www.railengineer.co.uk/2017/10/03/why-europes-busiest-railway-collapsed-at-rastatt/
[3] Van Leijen M 2018: Economic damage of Rastatt incident more than 2 billion Euros [25 Sep 2019]; Available from: https://www.railfreight.com/corridors/2018/04/22/economic-damage-of-rastatt-incident-2-2-billion-euros/
[4] Wolfgang b 2018: Rheintalbahn - Tunnel Rastatt - Chronik der Havarie und Sperrung 12.08. bis 02.10.2017 [17 Aug 2019]; Available from: https://www.youtube.com/watch?v=8EON4PphZsU&t=273s
[5] Forschungs informations system 2019: Historische Entstehungsgeschichte des deutschen Schienennetzes [05 Aug 2019]; Available from: https://www.forschungsinformationssystem.de/servlet/is/350049/
[6] Deutsche Bahn 2014: 20 Jahre Bahnreform und Deutsche Bahn AG Erfolge und künftige Herausforderungen 20
[7] Deutsche Bahn 2019: Anzahl der Mitarbeiter in der Deutsche Bahn AG in den Jahren 2005 bis 2018 (in 1.000). Date accessed 05 Aug 2019 https://de.statista.com/statistik/daten/studie/13591/umfrage/beschaeftigtenzahl-der-deutsche-bahn-ag/
[8] Holland 2019: Track star - Track Testing Solutions for All Conditions
[9] Mermec 2019: Inspizieren/Schieneninspektion
[10] PCB Piezotronics 2019 Sensos For Test & Measurements
[11] Deutsche bahn 2019: Open-Data-Portal [25 Sep 2019]; Available from: https://data.deutschebahn.com/dataset?groups=datasets
[12] Bahamon S 2019: Recognition of track defects through measured acceleration EACEF 2019
[13] Matlab 2019: Predictive Maintenance, Part 4: How to Use Diagnostic Feature Designer for Feature Extraction [25 Sep 2019]; Available from: https://de.mathworks.com/videos/predictive-maintenance-part-4-how-to-use-diagnostic-feature-designer-for-feature-extraction-1554458327719.html