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AN OVERVIEW OF RAILWAY INSPECTIONS AND WORK SAFETY. THE CASE OF GERMANY

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Abstract: *To always ensure the safety of goods and passengers, the railways must be kept in a secure state. Therefore maintenance (comprising inspections and repairs) is highly regulated in Europe's largest rail network, Germany. This article focuses on the legal framework of railway maintenance in Germany, while exploring the different types of inspections defined by the regulations. Furthermore, the article analyzes methods of ensuring work safety while inspections take place, by analyzing possible solutions in a tangible case.*
Key words: *Railway safety, railway inspections, German railway, railway maintenance, work safety*

1. INTRODUCTION

Railroad maintenance is a complicated subject, but it is critical to the continued availability of one of the most environmentally beneficial modes of transportation. Railway infrastructure maintenance entails a series of tasks that are difficult in more than one manner. Railways have strategic, economic, and military importance – therefore the infrastructure is held, managed, and maintained by the state in most European countries [1].

In Germany the infrastructure is owned and maintained by the German government through the state-owned company named Deutsche Bahn AG (abbreviated DB AG). DB AG is one of Germany's largest employers, with more than two hundred thousand employees in Germany and another one hundred thousand employees around the world.

The approximately 35000 km rail tracks in Germany (representing in fact Europe's largest rail network) are owned and maintained by DB Netz AG. This company is organized in 7 geographical regions (North, West, South, Southeast, East, Southwest and Center) comprised of 34 networks. Each of the networks administers roughly 1000 km of rail tracks and is usually based in one of the larger cities in Germany - for instance, the Kassel network owns and maintains the rail tracks in and around the German city of Kassel.

DB Netz AG is a public limited corporation whose shares are completely owned by the German government. The state contributes a portion of the company's annual budget in the form of a subsidy; however, this funding can only be used for track renewal and construction.

The company's own finances must be used to support track upkeep – inspections and repairs of existing lines. These funds are created by rail transport businesses renting time slots for the usage of the railway infrastructure. Internal DB firms (such as DB Fernverkehr, DB Regio, or DB Cargo) as well as third-party companies are subjected to the same regulations. If a rail transport firm needs to transport goods from Hamburg in northern Germany, to Basel in the neighboring country Switzerland, it must license use rights for all the rail tracks which will be travelled on.

To allow this train to safely traverse the entire distance, the traveled-on tracks, as well as the additional facilities required (such as overhead contact lines, level crossings, or signals), must be in good working order. This is accomplished through the maintenance process, which is DB Netz AG's core activity.

The inspection of the infrastructure is the first step in the maintenance procedure. The importance of thorough inspections cannot be stressed enough – not only in Germany, but in other countries (e.g., as shown in [2] or [3]) as well.

2. GENERAL ASPECTS OF RAILWAY MAINTENANCE IN GERMANY

While the EU laws and the German Basic Law concern general aspects which also apply to other infrastructure companies (like the national road maintenance company – Bundesautobahndirektion), it is on the third level of the pyramid that the first specific regulations for railway companies are formulated. The Allgemeines Eisenbahngesetz (General Railway Law, abbreviated AEG) points out that „[...] Railways are also required to build the railway infrastructure safely and keep it in a safe condition [4].

The operationally safe condition is given if:

- The system does not pose any simple operational risks (functionality);
- There are no general operational risks for third parties (traffic safety obligation);
- The risk due to increased operational risks is reduced (failure in a safe state).

Thus, it is easy to understand that the operational safety includes a comprehensive consideration of all risks.

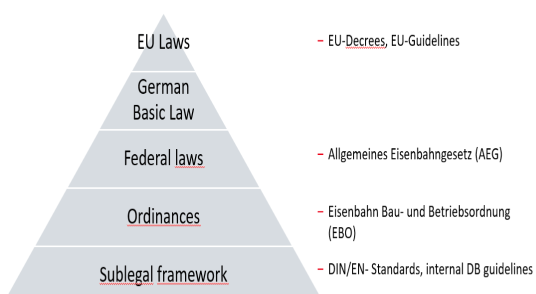

Fig. 1. Regulatory cascade regarding railway inspections in Germany.

The following levels of the pyramid (bottom two levels) substantiate this severe obligation formulated by the AEG. For instance, the Eisenbahn Bau- und Betriebsordnung (Railway building and operating regulations, abbreviated EBO) sets crucial guidelines which apply to nearly all tracks in Germany – a good example is the standardized gauge of 1435 mm and the extent to which a track is allowed to deviate from this value (minimum 1430 mm, maximum 1470 mm) [5].

The bottom level of this pyramid – the sublegal framework - is very specific: the DB internal guidelines (DB-Richtlinien) define in detail every aspect of the maintenance process, inspections and repair works alike. In the following sub-chapters, we will highlight the regulations influencing these two critical components of the process.

As different skills and knowledge are necessary to be able to inspect a railway signal or a track switch, there are three different departaments in every one of the 34 networks in Germany. These departments focus on the inspection and repairs in:

- Rail tracks and track switches;
- Structural engineering systems;
- Signals and level crossings;
- Overhead contact line.

Each of the departments is bound by specific rules and standards to conduct different inspections of the assigned facilities during a given period. Inspections have to be conducted by qualified personnel – some employees have to be qualified for as long as seven years before being able to conduct select inspections on their own.

3. THE CASE OF THE RAILWAY INSPECTIONS IN GERMANY

Inspections of rail tracks and track switches are complex and are carried out by several different means. These inspections are regulated in the Guideline 821 of DB Netz AG – the individual modules of this standard refer to different type of inspections [6].

Module 821.2001 refers to the planning, implementation, assessment, and evaluation of the track geometry with a special track measuring vehicle. These vehicles are fitted with a special technique that allows the train to travel on a track from station A to station B while continuously measuring the geometrical parameters of this track. These geometric parameters are recorded in a measurement output, which is continuously printed out on an on-board printer during the inspection.

Depending on the maximum speed allowed on the track segment, there are maximum values for every one of these parameters that cannot be exceeded. If they are exceeded, an operational limitation (like a speed reduction or even – in severe cases – a track closure) is necessary. A manager or a qualified representative is also present and quickly analyzes the measurement output to decide whether such an operational limitation is necessary. After the inspection the responsible district manager analyses the measurement output in detail and decides on necessary rail works or repairs [7].

The next module 821.2002 refers to the planning, implementation, assessment and evaluation of the technical driving inspection. This inspection regards the checking the interaction between the vehicle and the track in terms of driving safety, track stress and driving behavior for allowed maximum speed. This is achieved by measuring the forces between the train wheel and track rail as well as the accelerations on the bogie frame and in the vehicle body. [8] This module of the 821 guideline and the inspection defined here is only applied to tracks with maximum allowed speeds greater than 160 km/h or to tracks fitted with tilting technology (NeiTech).

One of the most important rail track inspections is regulated by the module 821.2003. This module regards the on-foot inspections by trained railway mechanics [9] During this inspection, a specially trained employee (the railway mechanic or foreman – a qualification obtained after roughly 3 to 4 years of working for the company, a team leader or even the district manager) walks the track and primarily visually inspects the condition of the railway superstructure – sleepers, rails and track ballast. In addition, the employee also must monitor the other railway systems he passes by (like the overhead contact line, signals or bridges). This additional task is justified by the fact that this type of inspection is much more frequent compared to all other inspections.

Module 821.2004 defines another inspection type – this time only conducted by the district manager himself. [10] This inspection is carried out riding on trains or end-cars on all tracks in the district. The purpose of this train ride is to carry out an inspection of the superstructure and the other railway facilities that can be viewed from the vehicle. During this inspection, the district manager can also identify deviations in the track geometry through their effect on the vehicle.

Another very important means of gaining knowledge regarding the status of rail facilities is the inspection defined by module 821.2005. [11] This module regards the inspection of track switches and crossings by measuring certain important parameters such as the track gauge with a mobile measuring device traveling on wheels. This device is pushed by a railway mechanic who constantly supervises the results. Just like in the case of the inspection defined in 821.2001, the employee must set operational limitations when certain values are exceeded. For instance, the track gauge must be at least 1430 mm and at most 1470 mm – any other value means the track has to be closed by the employee, as the transport safety cannot be guaranteed.

Module 821.2007 concerns the non-destructive testing of the rails with individual procedures for detecting internal and/or external rail defects, as well as the inspection of the rail head longitudinal and transverse profile to determine existing rail running surface defects. [12] The following measurement and testing methods are used for this inspection: visual examination, ultrasonic testing or eddy current testing, the latter two with hand probes, hand - held devices or rail inspection trains like the SPZ/SPF-ET/UT.

Figure 2 shows the operating mode of ultrasound inspections by rail testing-vehicles. The output of this inspection is a protocol of supposed rail defects. These supposed rail defects must be checked and confirmed by a foreman on site using ultrasonic testing with hand probes. Only about 50% of the supposed rail defects are confirmed and must be repaired by the infrastructure company.

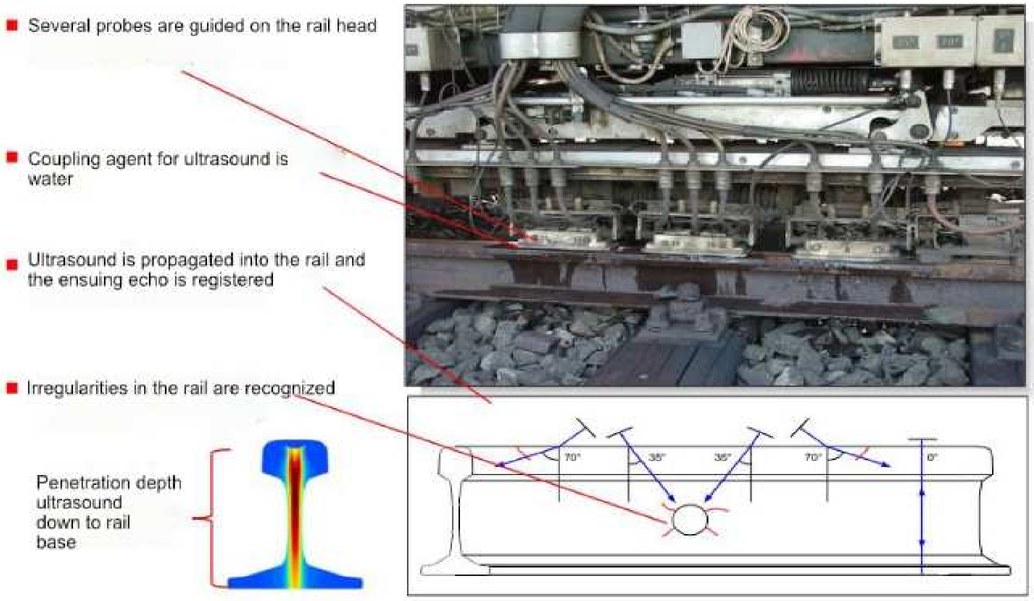

Fig. 2. Ultrasonic testing with rail testing vehicles (SPZ-UT) [10].

Tabelle 1: Regelinspektionsabstand der Hauptgleise Höchstgeschwindigkeit Hg nach VzG bzw. VzG NeiTech				
Hg ≤ 80 km/h[1)]	80 km/h < Hg ≤ 120 km/h	120 km/h < Hg ≤ 160 km/h	160 km/h < Hg ≤ 230 km/h	Hg > 230 km/h[2)]
18 Monate (ausnahms-weise 24 Monate)	12 Monate (ausnahms-weise 16 Monate)	6 Monate (ausnahms-weise 8 Monate)	3 Monate (ausnahms-weise 4 Monate)	3 Monate (ausnahms-weise 4 Monate)

Fig. 3. Extract from the DB Guideline 821.2001 regarding the inspection of the geometrical parameters of the track [7].

For most of the inspections regulated by the guideline 821, the frequency depends on the maximum speed of the track or track section. For instance, a track segment on which the maximum allowed speed is 100 km/h would be inspected regarding its geometrical parameters every 12 months.

If for any reason the inspection cannot take place within the given time-frame, the regulations stipulate a grace period within which the inspection must take place. For our example of a track with a maximum speed of 100 km/h, the inspection regularly takes place every 12 months with a grace period of 16 months. One of the reasons why the grace period could be activated is if, for instance, the inspection trains malfunction and cannot be repaired in due time. If the grace period for any reason should also not suffice, then the district manager must reduce the maximum speed of the track in such a way that the grace period is still respected. In the case, this would mean that trains travelling on this line could only travel at a maximum speed of 80 km/h instead of the 100 km/h regularly permitted. Once the inspection has taken place, the restriction is lifted again, and trains can travel again at 100 km/h (supposing there were no parameters exceeded during the inspection).

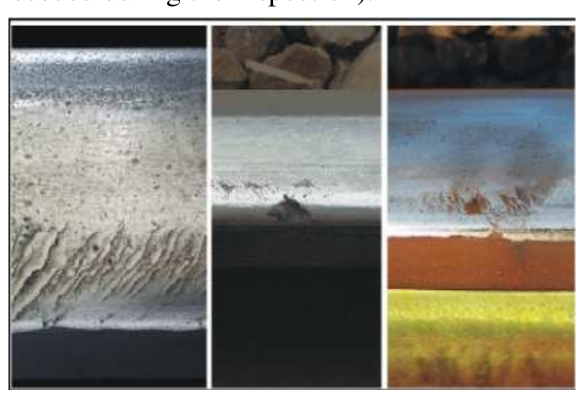

Fig. 4. Extract from DB Guideline 821.2005 on track switch inspection [11].

As we can see from the above guideline extract, the frequency of the inspection and the length of the grace period are inversely proportional with the increase in the maximum allowed speed. On high-speed tracks with speeds above 230 km/h (like Köln-Frankfurt with a maximum allowed speed of 300 km/h), inspections should take place as often as every 3 months and only one month of grace period is allowed before the maximum speed must be decreased to 160 km/h to comply with the regulations. If a track has track segments with different maximum allowed speeds, the highest speed is considered in determining the inspection interval. This means that the track segment from the example above with 100 km/h would be inspected after the regulations given for a track segment with a maximum speed allowed of 160 km/h if such a segment exists on this track.

There are similar regulations for the other inspections as well with a few important differences. For instance, the frequency of track switch inspections regulated by the DB guideline 821.2005 is influenced not only by the maximum speed allowed, but also by the registered daily load on the track switch. Based on both maximum allowed speed and daily registered load, track switches are divided into three categories. Categories 1 and 2 containing track switches with maximum speeds under 160 km/h must be inspected every 6 months, while track switches in category 3 (over 160 km/h maximum speed) must be inspected every 3 months (Figure 4).

The difference between inspections of switches in categories 1 and 2 is an aspect regarding the qualification of the employees tasked with these inspections – this also becomes apparent in the regulations of the on-foot inspections in Guideline 821.2003. While track switches in category 1 can be inspected by an employee or a foreman, the ones in category 2 must be inspected either by a foreman or by the team leader.

The regulations for the on-foot inspections also stipulate that the tracks must be inspected by the foreman, by the team leader and, every 24 months, by the district leader himself.

Belastungsstufe	1	2	3
Geschwindigkeit zul. v [km/h]	≤ 160	≤ 160	> 160
Lasttonnen/Tag	≤ 30 000	> 30 000	-
Regelinspektions-abstand	**6 Monate**		**3 Monate**

Fig. 5. Head Checks – degrees 1-2 [12].

There is only one of the presented inspections where there is no influence of the maximum speed allowed on the given frequency of the inspections. This is the locomotive inspection defined by the guideline 821.2004 - all tracks (regardless of their maximum speed) must be inspected by train ride every 4 months.

All the inspections (defined in the modules 821.2001 to 821.2007) aim to quickly discover track faults which could pose a threat to the safe and punctual rail traffic execution. Some examples for possible faults which would be discovered during these inspections are:

- Errors concerning the geometric parameters;
- Rail defects (such as Head Checks, shown in Figure 5);
- Cracked sleepers;
- Overhanging vegetation that alters vision on rail signals.

Inspections regarding signals and level crossings are always conducted through a visual and functional examination of the facilities (signals, level crossings, inductive train control systems). Special vehicles are not necessary for most of these inspections, which means that employees travel by car from their working base to the facilities and inspect on foot.

The only exception is when conducting inspections in tunnels – for these inspections the employees use a service train to arrive at the facilities; this train also serves as a lighting source during the inspection. The frequency of inspections of DB Netz AG signaling systems depends on the load on the relevant route.

For the overhead contact line, all inspections are performed with a special service train carrying a lifting ramp. This is necessary as the overhead contact line is located at a height of approximately 6 meters. Also, the inspection includes a visual and functional examination of the overhead contact line. In addition, there is an inspection conducted via a specially fitted service train, only in this case the contact wire position and the contact wire wear are measured. Figure 6 shows such a service train during an inspection (Figure 6).

Structural engineering systems such as bridges, earthworks or tunnels must also be inspected periodically. The inspection of bridges for instance is defined in detail by the DB guideline 804. Four types of inspections are defined herein [14]:

- Monitoring;
- Examination;
- Assessment;
- Special inspection.

The monitoring takes place during on-foot inspections defined by the guideline 821.2003 and only encompasses defects which can be seen from the railway track. The examination is carried out by the district manager, while the assessment is carried out by a technical expert. Special inspections are event-related and are carried out either by the district manager or by the technical expert. Both district manager and technical expert must be structural engineers with additional training.

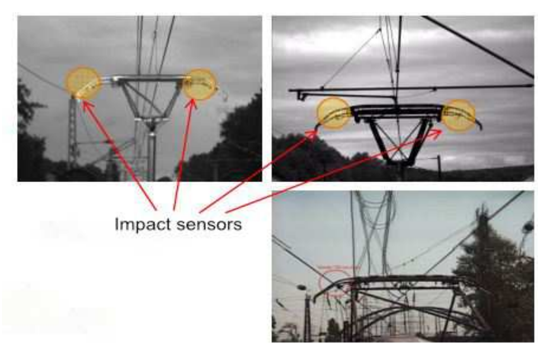

Fig. 6. Inspection of the position of the contact wire and wear of the contact wire [13].

After every inspection, the employee must create a report in the ERP system (this is SAP R/3 for the DB Netz AG). In this report the employee describes all found defects, while setting a maximum time frame (according to relevant guidelines and/or his experience and knowledge) in which the described fault or defect must be corrected or repaired.

These identified defects require different courses of action, heavily complicated by the fact that the second part of the maintenance process – the actual repairing of the railway infrastructure – in most cases must be very carefully planned to accommodate two problems not known from road maintenance: the impossibility of rerouting traffic and the narrow time intervals for the maintenance.

Whereas in the case of roadworks, traffic is easily diverted on another lane sometimes for months by placing the according road signs, this is infinitely more complicated in case of the railroad – leading to a narrow time frame for the repair works (usually 3 to 6 hours, at night and/or during weekends when traffic is reduced).

While some minor repairs can also take place without stopping train traffic in the relevant track (which means that the employees only work when there are no planned train journeys and interrupt their work for every train passing on this track), this is not a valid option in most cases.

Therefore, it is very important that the inspection reports contain as many details as possible regarding the necessary repair works to ensure a successful implementation, thus securing an improvement in the condition and availability of the critically important railway infrastructure. For instance, it does not suffice for the report to identify that a 12 m rail must be changed – other important information includes the exact position or kilometer on the track, any accompanying work that may be required, as well as preliminary work by specialist services such as the electrical department.

4. WORK SAFETY DURING INSPECTIONS

One of the most difficult components of the meticulous planning of railroad works is guaranteeing worker safety, as this domain still significantly relies on physical labor for upkeep. As illustrated, the better part of railway maintenance takes place while traffic is still possible, generally in the adjacent track and occasionally even in the track where repair work is being performed. It's understandable that determining the best course of action to safeguard the safety and well-being of the workforce is not always straightforward.

There are a variety of options for preventing mishaps during both phases of the maintenance process. Each course of action has its own set of benefits and drawbacks, as well as exclusion criteria.

When deciding on the best course of action, the decider (typically a railway company manager or a person authorized by the manager) always goes with the safest choice first. If an exclusion criterion is discovered, the decider considers the next most secure option until no exclusion condition for one of the choices is met. As a result, the workforce is always guaranteed the highest imaginable level of workplace security.

Table 1 shows the current options for work safety during inspections of the railway as stipulated in the German technical regulation 132.0118 [15] (Table 1).

Table 1

Options for ensuring work safety during railway inspections according to German regulations.

Course of action	Advantage	Disadvantage	Exclusion criteria
Automated notice system AKA-L90	Highest workforce security, no human fault possible	Only available on 2 tracks in Germany, system will be discontinued	None (if system is available)
Track closure for the time frame of the inspection	High workforce security, does not rely on additional actions by employees	Great impact on railway traffic, human fault is possible (e.g., operating error by train dispatcher)	High train traffic values which do not allow a track closure
Notice of train approach	Relatively secure for the workforce, as trains can only be allowed on the track after having informed the foreman of the workforce, no impact on train traffic	Heavy workload and responsibility for the train dispatcher, human fault is possible	Too high workload of the train dispatcher, only usable between train stations
Safe interpretation of train approach signs	No impact on train traffic	Heavy workload and responsibility for the workforce, as the employees need to stop working and leave the working track after interpreting the signs of a nearing train	Not usable for train speeds above 200 km/h, train approach signs can only be interpreted in select locations (e.g., near a level crossing)
Safe sighting of incoming trains	No impact on train traffic	Extremely dangerous, heaviest workload and responsibility for the workforce	Not usable for train speeds above 200 km/h, approaching trains can only be duly sighted in select locations (with unimpaired visibility)

As can be seen, several factors influence the decision regarding the safest possible course of action, the most important of which are:

- Maximum allowed speed;
- Train traffic values;
- Workload of train dispatcher;
- Nearby railway facilities (e.g., level crossing) [1];
- Necessary time frame for the inspection;
- Location in the railway network;
- Technical equipment of the route.

For an inspection defined by the guideline 821.2003 (the on-foot inspection), several of the courses of action could be taken into consideration. To correctly assess the exclusion criteria, the decider first has to acquire all necessary information – in fact the listed factors. In this case study we will analyze an on-foot inspection on the track 3900 (Main-Weser-

Railway, running from Kassel to Frankfurt), between the Borken (Hessen) and Zimmersrode stations. The maximum allowed speed in this section is 150 km/h and the inspection is carried out by one employee during a sunny day with clear skies.

As the process requires, the decider would start with the highest possible level of security – this being the level 1 course of action describing the use of the automated notice system AKA-L90. This is however precluded by the fact that the system is not installed on the track 3900 – as it was only ever installed on two tracks in Germany (the 4080 from Mannheim to Stuttgart and the 1733 from Hannover to Würzburg). Had the system been installed on the 3900 we considered for this example, it would have certainly been the best option: with the AKA-L90, the workplace (even if it is a track section like in our example) is included in the interlocking logic of the signal box as an element of the route and is therefore directly involved in determining the route for an approaching train. [16] This means that the train dispatcher is actively prevented from allowing trains to enter the occupied section of track.

Having excluded the level 1 option, the decider carries on to the level 2 option: the track closure for the time frame of the inspection. This course of action means that the deployed employee reports to the train dispatcher and applies for the blocking of the route in the corresponding section for reasons of accident prevention.

This measure is still relatively safe for the inspector, since the dispatcher himself prevents the trains from entering the section of track, but not as safe as the AKA-L90, as human faults are still possible. The exclusion criteria listed in Table 1 is met in this case, as the track 3900 has objectively very high traffic values which only allow short track closures of about 5 to 10 minutes – insufficient for the efficient completion of the inspection.

The next course of action is the level 3 method „Notice of train approach" – meaning that the train dispatcher must actively inform the inspector about incoming trains. The exclusion criteria herefor is also met, as the high traffic values of the track also equal heavy workload for the train dispatcher.

The safe interpretation of train approach signs cannot be used in this case – this course of action only applies as stated in the table above in select locations, like near level crossings (whose closing barriers clearly indicate an approaching train). For the chosen example, the inspection takes place in a track segment and is perpetually moving, thus rendering this option unusable.

The last option is the course of action which can be used in the analyzed case: the inspector can apply by phone with the train dispatcher for the exclusion of trains running against the usual direction of travel and then move towards the trains coming from the only possible direction. If the visibility is good (no rain/snow, no restricted visibility due to curved tracks), the employee can recognize an approaching train in due time and leave the track area quickly, before the train passes his current place. This places a high workload on the inspector, as he is solely responsible for his own safety, but is a method that can be used nearly on all tracks and which does not greatly impact incoming train traffic. The exclusion of trains running against the usual direction of travel is here of great importance to the employee, as it means he only has to reckon with trains coming towards him - there is no risk of a train coming from behind. The impact on train traffic is reduced, as trains rarely use the opposite track (thus traveling against the usual direction of travel).

In practice, this method is combined with the measure of track closure, e.g., to be able to walk safely on curved tracks. This means that the employee applies for a track closure as soon as his visibility is negatively affected by the curved track, uses the track closure (of about 5 to 10 minutes, or multiple such natural train breaks) to walk along the curved track and then lifts the blockage again - the safe sighting of the incoming trains is then used again. The same strategy applies if the weather conditions should deteriorate during the inspection, e.g., due to the onset of rain, snow or fog.

Were one of the exclusion criteria of the last possible course of action to be met, then the entire decisional process must be repeated under changed terms and/or conditions, until one of the options can be used.

It is not easy for the decider to correctly assess all the information, especially since the same analysis must be performed numerous times for both working and neighboring tracks. In the analyzed case of the on-foot inspection on the DB track 3900 this is however not relevant – the employee only moves in his work track or steps out of the track on the track-free side without ever having to enter the danger zone of the neighboring track.

This risk assessment may significantly differ in the case of other inspections or inspections of other systems (e.g., switches in a train station). Furthermore, some inspections can also only take place in teams of employees – in this case it is necessary that the chosen course of action ensure the safety of all of them, as opposed to the example in this article where only one employee was tasked with the on-foot inspection.

When we consider the necessity of documenting the decisions made, the arguments or exclusion criteria for these decisions, as well as all other general relevant information for the employees (such as dispatcher or supervisor telephone numbers, day and time, maximum speed, etc.) in a specially designed, fixed-layout, paper-bound form [17] called safety plan, it becomes clear that completing this task successfully is a serious challenge.

A management control system for job safety is also in place at the German railway operator DB Netz AG. All supervisors and executives are required to conduct a specified number of on-site controls under this control scheme (ranging from at least two per year to as often as once every month).

During these checks, the managers use a checklist to ensure that the safety-related specifications are met, as well as the implementation of the previously mentioned safety plan. Some of the items on this checklist are related to the proper implementation of the decisional process (such as the right identification of the exclusion criteria for higher-level security measures), but others are related to the way employees abide by the regulations stipulated in the safety plan or concern the wearing of special clothing by employees.

5. CONCLUSIONS

The German regulations define in detail which inspections must be carried out, also establishing time frame and necessary qualification of the employee tasked with them. The aim of the extensive inspections is the early identification of defects that require assessment and the determination of maintenance requirements, from which measures to maintain infrastructure availability can be derived.

Railway inspections must be carefully planned, as ensuring the safety of the employees is no trivial task. Risk analysis is the most important part of the work safety process – the manager tasked with ensuring the safety of his employees must take into consideration all relevant factors and abide by the complicated decisional process.

Planning alone is however insufficient – it is also crucial for the well-being of the employees, that these closely follow the chosen courses of action and respect a set of ground rules such as not stepping on rails or not using a phone while in the danger zone.

There is no doubt about it that inspections represent the backbone of the quality maintenance of the German railway infrastructure, thus playing an essential role in the safety of railway traffic in this country, particularly, and in Europe in general.

The challenges for the future lie in the digitalization of railway inspections, as the current system is too labor-intensive and furthermore subject to possible errors. The solution to these problems could be railway inspection robots with artificial intelligence (as suggested in [18] or [19]) or prediction models.

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O analiză a inspecțiilor la calea ferată și a securității muncii în timpul acestora în Germania

Pentru a asigura în orice moment siguranța mărfurilor și a pasagerilor, căile ferate trebuie menținute într-o stare sigură. Acesta este motivul pentru care întreținerea (cuprinzând activități de inspecții și reparații) este detaliat reglementată în cea mai mare rețea feroviară din Europa, cea din Germania. Acest articol se concentrează pe cadrul legal al întreținerii căilor ferate din Germania, explorând în același timp diferitele tipuri de inspecții reglementate de cadrul legislative-normativ actual. În plus, articolul analizează metode de asigurare a siguranței muncii în timpul inspecțiilor prin intermediul unui exemplu concret al unei inspectii uzuale la calea ferată.

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