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SUSTAINABLE RAILWAYS – INVESTIGATION OF THE ENERGY EFFICIENCY OF ELECTRIC RAIL VEHICLES

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Abstract *– This paper investigates the energy efficiency of electric rail vehicles, focusing on factors that promote more sustainable railway systems. Using real-time data from Siemens Ventus trains operating between Vienna-Deutschkreuz and Vienna-Bratislava, the study analyzes how regenerative braking, infrastructure quality, and driver behavior affect energy consumption. The data were processed to evaluate energy consumption and pinpoint areas for potential efficiency improvements. The results demonstrate that regenerative braking and energy storage systems substantially reduce energy consumption, although external factors, such as track conditions and operational strategies, introduce variability in consumption. These findings support the development of energy-efficient railway operations in line with the European Union's sustainability objectives.*

Keywords – electric rail vehicles, electric multiple units, energy efficiency, regenerative braking, sustainable railways.

1. INTRODUCTION

This study explores the energy efficiency of electric rail vehicles, an essential factor in fostering sustainable railway systems, aligned with the EU's focus on environmentally sustainable, multimodal transportation [1]. Technological advancements, such as regenerative braking systems, enhance energy efficiency by transforming kinetic energy into reusable electrical power, reducing total energy consumption by as much as 45% under specific conditions. [2,3].

Integrating energy storage systems further enhances efficiency by capturing energy otherwise lost during braking [4]. Effective energy management requires a comprehensive approach that includes infrastructure quality, operational strategies, and driver behavior, which can significantly impact energy savings [5].

The research is partly related to optimizing train schedules and energy usage. Driver Assistance Systems (DAS) improve punctuality and efficiency through real-time data, reflecting the industry's commitment to sustainability. The study analyzes Siemens Ventus electric multiple units' energy consumption on routes between Vienna-Deutschkreuz and Vienna-Bratislava in early 2023. It identifies four primary factors affecting energy efficiency: infrastructure, regenerative braking, external factors, and human behavior [6].

While data limitations hindered a detailed analysis of driver styles, the study provides valuable insights into energy consumption and supports efforts to enhance rail transport sustainability [6].

2. APPLIED METHODS

This article analyzes data sourced from the on-board computers of Raaberbahn trains operating on the Vienna-Deutschkreuz and Vienna-Bratislava routes from January to May 2023. The data, provided in bulk Excel files from Siemens Ventus trains includes the following key points.

The data structure comprises five monthly data series recorded at 5-minute intervals, capturing details such as train numbers, GPS coordinates, and cumulative electricity consumption. Specific data points, including precise speeds, acceleration and deceleration times, and driver identities, are missing.

Supplementary data: the segment numbers for stations and stops were obtained from Raaberbahn and ÖBB reports, and GPS coordinates were determined accordingly. Speed limits for each section were sourced from ÖBB, Raaberbahn AG, and public data available on www.openrailwaymap.com.

Data processing: the trains were mapped to specific routes based on GPS coordinates. A Python program calculated distances between data points and determined the direction of travel. The data was filtered to focus on energy consumption and regenerative

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braking energy within a ±2 km range of stations, considering the direction of travel. The methodology outlines the process of focusing on data points within this ±2 km range around stations.

Statistical analysis: Excel files were generated with multiple worksheets for specific routes, calculating metrics such as minimum, maximum, average, standard deviation, and relative standard deviation for energy consumption and regenerative energy recovery.

The analyses were conducted using data from three different train datasets, covering the routes illustrated in Figure 1.

The datasets contain a month's worth of data, recorded at 5-minute intervals, and include GPS coordinates, time, energy consumption, and regenerative energy data. The data was stored based on time rather than distance, meaning that while continuous data was captured, the relationships between consecutive data points were not pre-defined.

Given that the bulk data represents trains operating over multiple sections, the first step in processing was to assign these sections to specific routes using GPS coordinates to determine both the route and the direction of travel. A reference line was established for each route. Distances from stations were recorded in a lookup table, with distances between points set at 50 meters. Subsequently, the incoming GPS coordinates were assessed to determine the distance from the departure station, allowing the train's real-time position to be calculated.

Fig.1. Map of the section to be analyzed with the railway stops

The data was then organized in alignment with the railway schedules, which included travel times, energy consumption, and regenerative braking energy values. It is important to note that these values represent instantaneous conditions.

Figure 2 illustrates the data points corresponding to each section. The x-axis (horizontal) represents the distance traveled, while the y-axis (vertical) shows the energy consumed. It is important to note that the energy values do not account for any deductions from regenerative braking. The numbered markers and vertical lines on the charts represent station locations. The data from different trains are represented by distinct colors: blue for train 300, gray for train 301, and yellow for train 303. The red line indicates the proportional average energy consumption.

The scatter plot reveals that many data points are either significantly above or below the average. Furthermore, there is no section where energy consumption consistently deviates significantly above or below the average.

Key considerations and unaddressed limitations include the following.

The analyses did not use machine manual data or other tractive force curves to calculate Siemens Ventus trains' acceleration and regenerative braking energies, nor were the measured values considered.

The analyses did not discuss or use the railway lines' layout and vertical geometry data.

The authors did not use official train timetables for each route and direction, and rolling axle load values were disregarded.

The allowed speeds for each section, presented in Section 2.1, were included for informational purposes only and were not factored into the detailed analysis.

The technical condition of the railway track and associated infrastructure (e.g., overhead contact line network) or the traction units (whether in poor or good condition) was also not considered.

The analyses relied solely on data from January to May 2023, and no attempt was made to extrapolate this data to estimate values for other months; the analysis is, therefore, based entirely on factual data from this period.

Each month was treated as a separate unit (without merging data), and energy consumption (kWh+/km) and regenerative braking (kWh–/km) values were analyzed separately for each month.

3. RESULTS AND DISCUSSION

The analyzed route between Vienna and Bratislava includes 11 stops, though trains do not stop at every station. The energy consumption data is presented in aggregate form, but the available information does not allow for determining the exact time spent at each stop. The main goal of this analysis is to observe average energy consumption across different segments and identify the factors affecting it.

Section A) of Fig. 3 shows cumulative energy consumption, highlighting the maximum and minimum values, while Section B) presents the average distribution, showcasing variability across segments. This helps pinpoint areas where consumption is unstable and requires further investigation. Section C) shows energy consumption per kilometer, indicating which segments consistently have higher average consumption, often due to inclines or initial delays. Section D) details the energy recovered through regenerative braking, giving a complete view of the regenerative contribution.

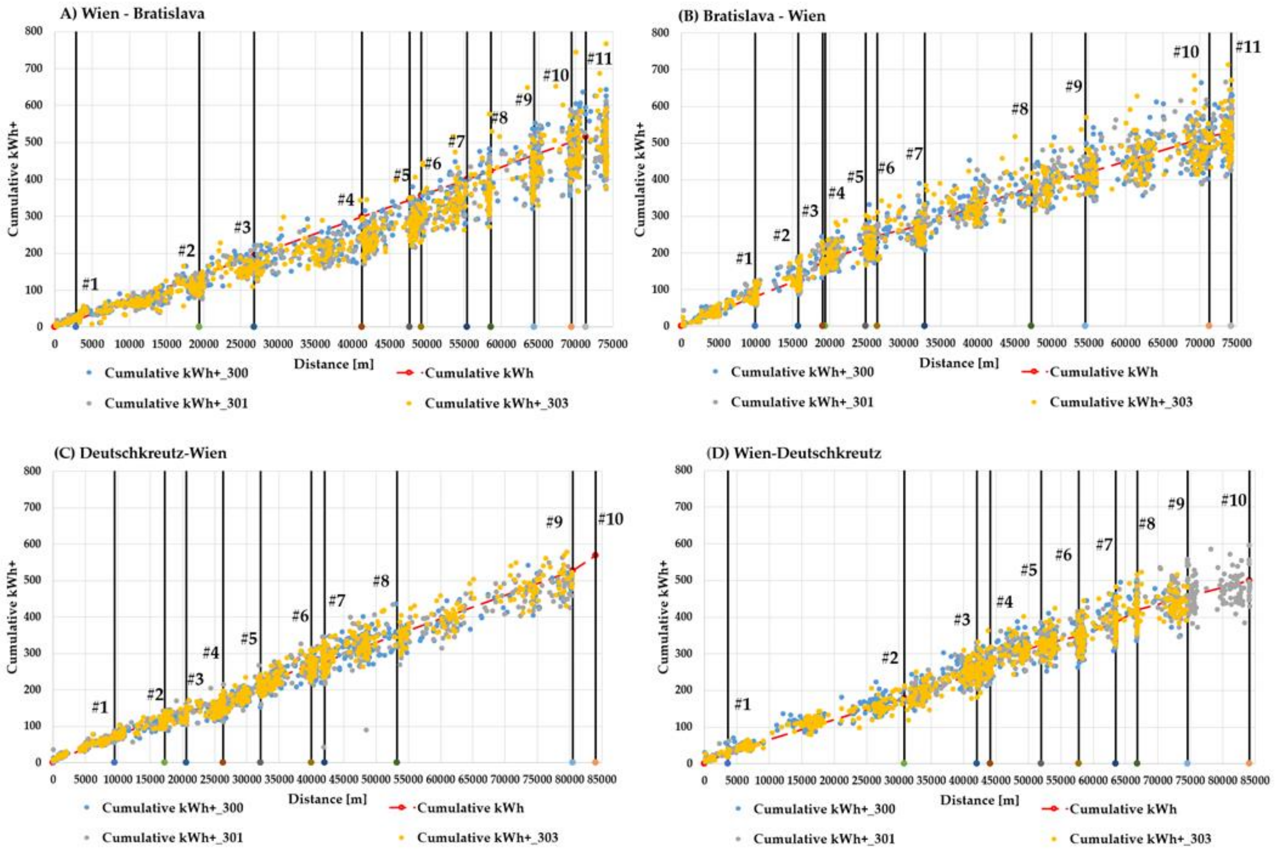

Fig.2. Stops and associated consumption data for each railway line (chainage "0" means the beginning section)

This method clarifies energy imbalances and allows for fitting curves to each segment's average consumption, generated energy, and total consumption. These curves reveal where and why energy balance deteriorates and help identify sections with the highest energy demand. The method can also detect track issues and areas of higher-than-average consumption. External factors like unplanned waiting times can also be spotted. Regenerative braking efficiency depends on how much energy the network absorbs, but larger datasets help account for this. Even the train operator's influence can be observed in lower regeneration or larger analyses. Curve fits from these evaluations are shown in Figure 4.

4. CONCLUSION

This study offers a detailed look at the energy efficiency of electric rail vehicles, focusing on the role of regenerative braking systems, infrastructure quality, and operational practices. Essential trends in energy use can be identified by examining critical factors like energy consumption, regenerative energy recovery, and overall energy balance for different rail segments.

The findings show that regenerative braking and energy storage systems significantly enhance efficiency. However, external factors like railway track conditions and driver behavior introduce variability in energy savings. The current analysis reveals that when energy consumption surpasses 110% of the average, even high levels of regenerative energy recovery are not enough to offset the increased demand.

This highlights the need for a comprehensive approach to managing railway energy consumption that combines technological innovation with optimized operational strategies. Going forward, efforts should focus on reducing the influence of external factors and refining predictive models to optimize real-time energy usage better.

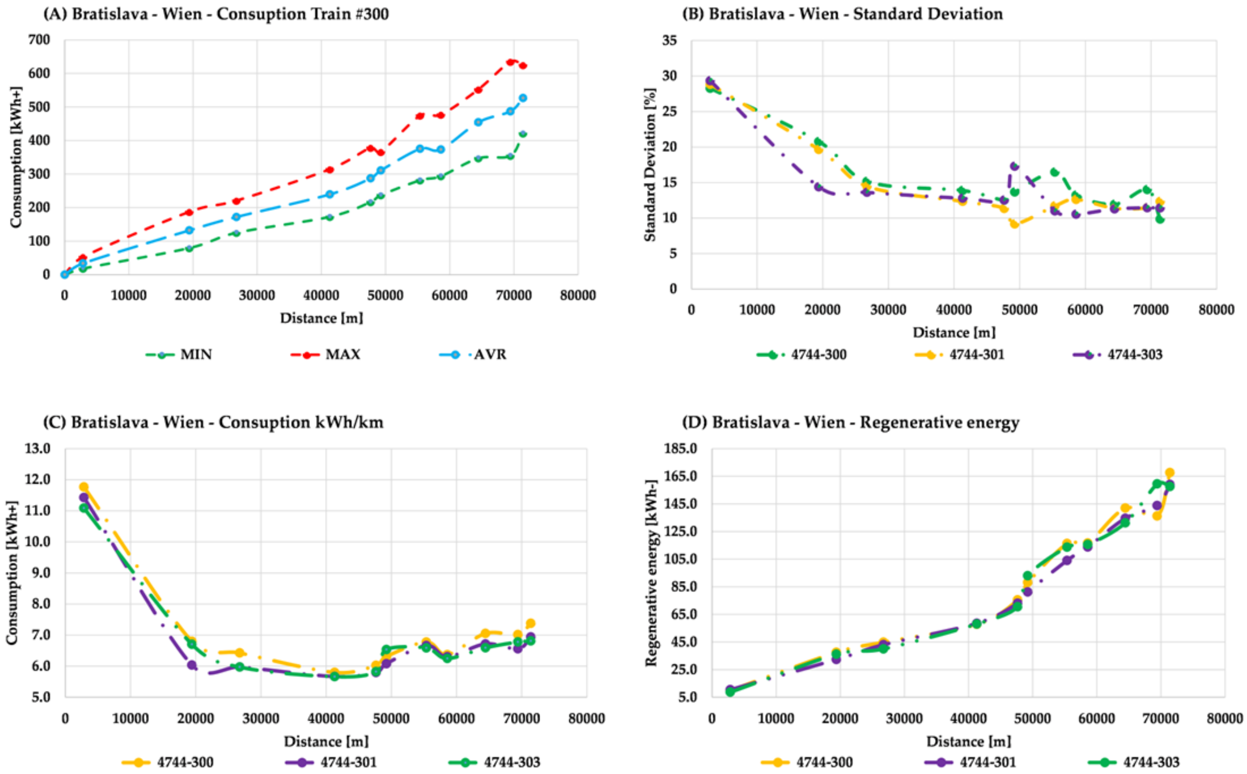

Fig.3. Analysis of consumption and approaches to energy efficiency in rail

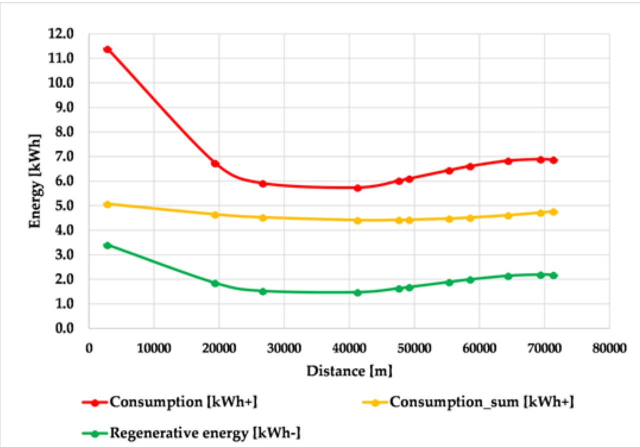

Fig 4. Curve fits obtained from the evaluation of the measurements

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EVALUATION OF RIDE COMFORT FOR PASSENGERS OF A MULTIPLE-UNIT TRAIN WITH DIFFERENT TYPES OF POWERTRAIN

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Abstract *– Multiple-unit trains belong to quite widely used passenger railway vehicle, which transport passengers usually for medium long distances. There is suburban and intercity passenger railway transport. Multiple-unit trains with independent traction are applied on railway lines, where electrification is not available. Current diesel multiple units (DMU) are exposed to stricter and stricter requirements for their carbon footprint. Therefore, producers of DMUs are forced to think about alternative fuels and power sources, which are more environmentally friendly during operation. A hydrogen powertrain system of a DMU is one of perspective ways to reduce negative effects of operation of conventional diesel combustion engines. As an installation of new source of power to an existing DMU design represents a significant change of its structure, it is important to evaluate the main running properties of a modified vehicle. The goal of the presented research is to evaluate the dynamic properties of a DMU with different types of powertrains. The dynamic properties are assessed by means of the indices of ride comfort passengers. This requires knowing values of accelerations on chosen location in a DMU body. The research was conducted in a commercial multibody software. The results have shown that an installation of the hydrogen powertrain does not significantly influence the dynamical properties of the investigated DMU.*

Keywords – suburban train unit, railway vehicle, powertrain, multibody system, dynamics.

1. INTRODUCTION

Current demands to the emission reduction of transport means force producers to find new and innovative technical solutions, which allow to reduce a production of harmful exhaust emissions during operation. These demands also relate with railway transport. Electrification is one of a possible way. However, there are locations and regions, where electrification of railway lines is not possible, or it is not effective. Therefore, rail vehicles with an independent powertrain are used [1]. These rail vehicles are powered by a diesel combustion engine, and they form train-sets consisting of a locomotive and wagons or they are complete units called multiple units (MU). The second variant often appears, because it provides several advantages. However, they are also powered by diesel combustion engine producing unwanted exhaust emissions including CO_2.

Recently, there are way of reduction of gas emissions production. An application of batteries does not provide a sufficient running range of a rail vehicle [2]. More modern and current way is an application of hydrogen fuel cells as a source of energy for a rail vehicle [3-6]. A rail vehicle, namely the MU with an installation of hydrogen fuel cells is a subject of this research. Originally, the solved MU is a DEMU (it means, diesel-electric multiple unit) (Fig. 1). The modified vehicle includes an installation of a new, modern and ecological powertrain, which uses fuel cells as a source of energy. However, this modification requires a significant change of the DEMU design. It is a change of unnecessary

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components of an original diesel-electric powertrain and an installation of new components, which will ensure flawless operation of the unit with the hydrogen fuel cells.

Fig.1. An illustration of the solved multiple unit train

The point of the solved issue consists in a fact, that the component of the multiple-unit with the hydrogen fuel cells have higher mass. Therefore, it is assumed a significant influence on the running properties. Based on this fact, it is necessary to perform needed analyses which reveal the results about the running properties. From the running properties point of view, running safety and ride comfort for passenger is assessed. The analysis of running safety is an object of other research, which results are also included in this proceeding. The ride comfort of passengers is a parameter, which belongs to the vehicle dynamics. The fuel cells components increase the total weight of the multiple unit train. This fact is evaluated form the ride comfort point of view.

2. RIDE COMFROT FOR PASSENGERS

Ride comfort for passengers in rail vehicles is one of the most important dynamic properties of these transport means. It can influence passengers, whether they choose that which vehicle and then, a producer an operator (or the transport company) can choose a product of the particular producer. Ride comfort for passengers is a complex of factors, which a passenger is exposed, such as noise, light, and mainly vibration [7, 8].

Regarding to dynamics, the ride comfort for passengers is affected by vibrations, which arise during rail vehicle running on a railway track [9, 10]. These vibrations are generated mainly by track irregularities as well as due to running through other parts of track (e.g. through turnout).

Based on described above, the ride comfort for passengers takes into account the intensity and level of track irregularities as an input to the mechanical systems of a rail vehicle. The evaluated and assessed output from the mechanical system are accelerations. These acceleration signals are measured in specified locations of a rail vehicle. There are recognized several main locations of accelerations detection together with the method of evaluation of the ride comfort for passengers.

For the purposes of the presented research, the N_{MV} ride comfort index in a chosen places of the multiple unit train is calculated and evaluated. The N_{MV} comfort index related with the locations on a floor and it is calculated based on the following formulation [11-13]:

$$N_{MV} = 6 \cdot \sqrt{\left(a_{xP95}^{W_d}\right)^2 + \left(a_{yP95}^{W_d}\right)^2 + \left(a_{zP95}^{W_b}\right)^2} \qquad (1)$$

where a_x, a_y and a_z are accelerations in the x, y and z directions, respectively, $P95$ means the 95-percentage and W_d, W_b are weight functions.

Hence, the investigated multiple-unit train were analysed for specific operational conditions (track geometry, running speeds, track irregularities), at which, both an original version (with a diesel-electric powertrain) and a modified version (with a hydrogen fuel cells powertrain) were assessed.

3. A MULTIBODY MODEL OF THE MULTIPLE-UNIT TRAIN

A multibody model (MBS model) of the solved multi-unit train was created in the Simpack software in order to perform the needed simulation computations. The set-up MBS model interprets all specific characteristics of the rail vehicle. As it can be seen in Fig. 1, the vehicle consists of three articles, which rest on four bogies. Two bogies belong to end articles and two bogies, so-called Jacobs bogies, are mutual for middle and end articles. The primary suspension connects wheelsets axle boxes with the bogies frames and includes coil springs and hydraulic dampers. The secondary suspension is located between articles bodies and bogies frames. It includes air-springs and additional hydraulic dampers. Used air-springs improve the ride comfort for passengers and allow to maintain the constant floor height independently on the load. The created multibody model of the solved multiple-unit train is shown in Fig 2. In this figure, five pints are marked. These points were selected for evaluation of the ride comfort for passengers. Surely, all tree articles serve for transport of passengers. However, the range of the paper does not allow to present the findings for the entire vehicle. On the other hand, the performed research has shown, that the most unfavourable response to the excitation seems to be in the first article in the running direction.

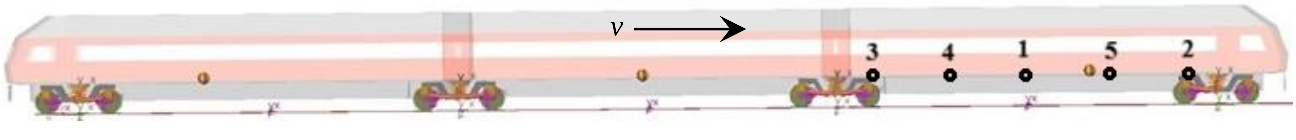

Fig.2. An illustration of the MBS model of the solved multi-unit train with marked measured points

Simulation computations were performed on a track model, which corresponds to the real railway track section Prievidza - Chrenovec in the Sovak Republic. The track model included the track irregularities and with the Fastsim wheel/rail contact. The total length of this track section is of 9.8 km. The track profile together with the curvatures is shown in Fig. 3.

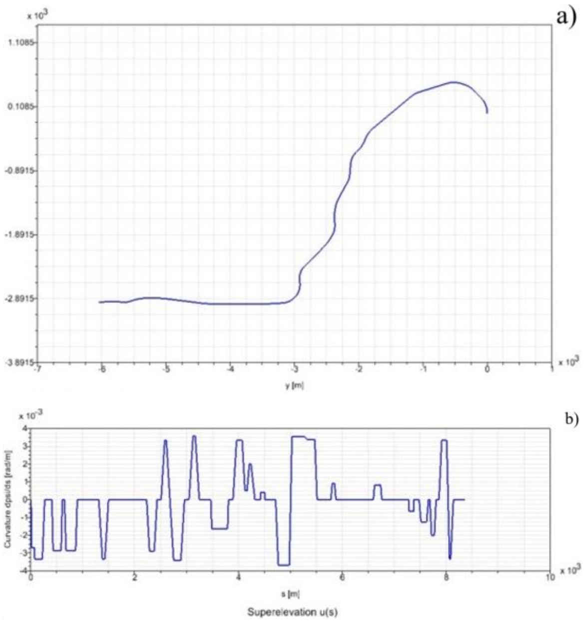

Fig.3. A horizontal profile of the track a) and the track curvature b)

The next section includes the results of the simulation computations. There are evaluated the results of the multiple-unit train running at the two speed of 50 km/h and 70 km/h on the railway track described above for both original and modified version.

4. RESULTS AND DISCUSSION

The presented results include bar graphs of the ride comfort index N_{MV} for five points (Fig. 2) in the original vehicle (with the diesel-electric powertrain) and in the modified vehicle (with the hydrogen fuel cells powertrain).

Fig. 4 shows the distribution of the N_{MV} index for the original vehicle at the speed of 50 km/h. As it can be seen, the highest values of the index are in the ends part of the vehicle article and the smallest values are in the middle part - point 1. From the human sense, it is "very comfortable".

The results of the N_{MV} index for the modified vehicle and the running speed of 50 km/h is shown in Fig. 5. As it can be identified, the modified vehicle reached slightly higher values of the N_{MV} index in comparison to the original one. The vehicle is still evaluated as "very comfortable".

The results of the simulation computations for the running speed of 70 km/h are shown in Fig. 6 and Fig. 7, at which, the N_{MV} index distribution of the original vehicle is shown in Fig. 6. The values of the N_{MV} index are higher in comparison with the running speed of 50 km/h. From the total evaluation of the vehicle, it is evaluated for all five points as "very comfortable".

The last graph depicted in Fig. 7 shows the distribution of the N_{MV} index for the modified vehicle also at the running speed of 70 km/h. From the results, the modified vehicle reaches even slightly better values of the ride comfort index in comparison with the original vehicle. It is also ranked as "very comfortable".

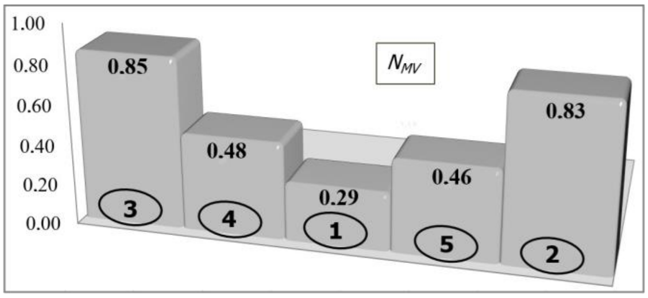

Fig.4. The ride comfort index in the original vehicle, 50 km/h

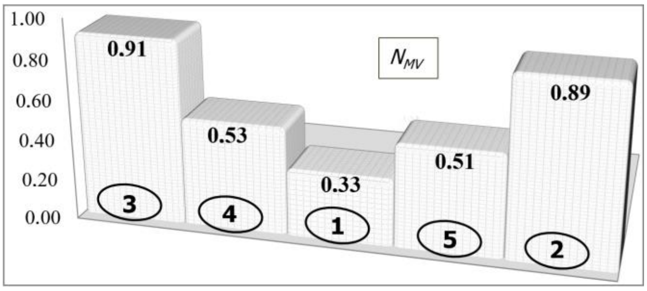

Fig.5. The ride comfort index in the modified vehicle, 50 km/h

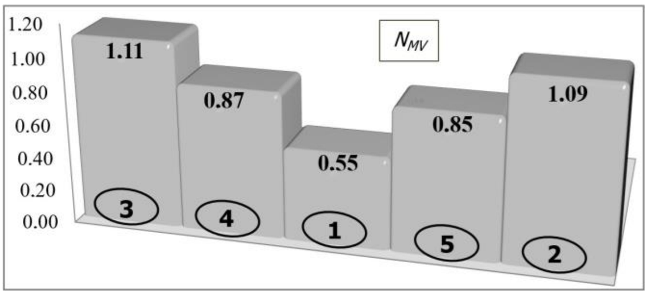

Fig.6. The ride comfort index in the original vehicle, 70 km/h

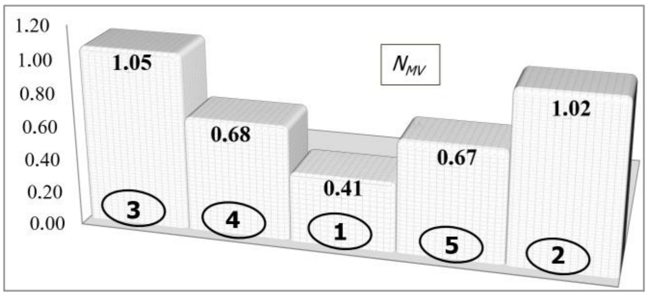

Fig.7. The ride comfort index in the modified vehicle, 70 km/h

The short discussion of the reaches results can conclude the following main findings:

- The ride comfort in the original vehicle and in the modified vehicle is comparable, the ride comfort for both vehicles is ranked as "very comfortable" for both chosen running speeds as well as for all five chosen measured points,
- All measured cases revealed that the highest quality of the ride comfort is in the middle of the vehicle article and lowest quality is at the end part of the vehicle article,
- The modified vehicle with the hydrogen powertrain does not show significant changes of the ride comfort level compared to the original one despite the changed total weight, therefore, the suspension system of the solved multiple-unit train does not need modification form the ride comfort point of view.

5. CONCLUSION

The presented research was focused on evaluation of the multiple-unit train from the ride comfort for passenger point of view. The main goal of the work was to assess, how the ride comfort for passenger is changed and influenced by the fact, that the original diesel-electric powertrain is replaced by the new hydrogen fuel cells powertrain. This modification of the powertrain changes the total weight of the multiple-unit train, therefore, it was an assumption, that this important factor will be affected. The performed simulation and calculation for the ride comfort for passengers shown, that the new powertrain does not significantly influences the comfort for passengers and form this point of view, the change of the powertrain does not require essential modifications of the suspension parameters.

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USING OF SATELLITE DATA FOR RAILWAY INFRASTRUCTURE MONITORING

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Abstract *– Structural stability and operational safety of transport structures, including railways and bridges, can be ensured by continuous monitoring of these structures and their surrounding environment. Several satellite remote sensing technologies have proven to be suitable for this task in the last few decades. This study conducted a review of literature on using satellite data for railway infrastructure monitoring, with respect to the application/use-case, and used satellite technology.*

Keywords – earth observation, satellite, monitoring, railway infrastructure.

1. INTRODUCTION

The use of Earth Observation (EO) for railways has been increasing in recent decades. In this context, EO data are normally those acquired from remote sensing platforms, such as Global Navigation Satellite Systems (GNSS) [1]. Data from EO satellites is transforming rail operations by providing insightful analysis, identifying problems before they escalate and optimising operational efficiency. Advanced satellite sensors delivering detailed EO data, combined with AI, enable rail network management to become more efficient, effective, and safer.

This paper provides review of literature on using satellite data for railway infrastructure monitoring. Review of literature with respect to the application/use-case, as well as a review with respect to used satellite technology is given.

2. USING OF EARTH OBSERVATION DATA FOR RAILWAY INFRASTRUCTURE MONITORING

The published papers can be grouped with respect to use-case for railway operators. EO was used for monitoring of rail track deformations, vegetation and water level around the rail track, ground deformation, railway transition zones, and railway bridges.

Increased traffic, combined with higher speeds and axle loads, impacts the rail track geometry. Therefore, early detection, identification, and analysis of potential deformations along rail track is of crucial importance [2]. Chang et al. [2] presented a methodology for fine-tuning satellite radar interferometry to railway infrastructure for near-real-time monitoring of changes in the rail track geometry. The same technology was used for monitoring rail track deformations over the entire railway network of the Netherlands [3]. Specht et al. [4] presented a complex method for the evaluation of the GNSS measurements for the purpose of rail track geometry assessment. Chang et al. [5] used categorized sub-structures of the improved Sentinel-1 derived Persistent Scatterers (PS) to identify deforming railway structures. Persistent Scatterer Interferometric Synthetic Aperture Radar (PSInSAR) technique with high-resolution TerraSAR-X satellite images was also

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used to measure and analyse deformation at the operating rail track in South Korea [6].

The vegetation on the railway network must be efficiently controlled to ensure the safety and regularity of train traffic, as well as the good condition of the railway infrastructure. Satellite data can be used to get a detailed inventory of railroad areas, by extracting of rail tracks, separating of different states of plant succession, or differentiating between surface types with varying degrees of impermeability, at appropriate scales for urban ecological monitoring and assessment [7]. Kučera and Dobesova [8] presented a method using satellite image data to identify the degree of threat to railway infrastructure in Czech Republic from falling trees according to three parameters: the height of tree stands, species composition, and vegetation health. Satellite image data and machine learning algorithm were used for supervised classification of vegetation on the French railway network [9].

The level of water near a railway track is a major factor affecting the safety of train passage and cargo. Arroyo-Mora et al. [10] proved that comprehensive information at multiple scales consisting of Unmanned Aerial System (UAS) data and satellite image data can be used to detect and monitor fine scale changes of water area and level around railway tracks.

The condition of the railway substructure is critical for the longevity of rail tracks. In recent decades, various non-contact monitoring and analysis systems for ground deformation have been developed [11]. PSInSAR patented by the "Politecnico di Milano", an efficient tool for high precision monitoring of deformation of the Earth's surface based on the use of a time series of satellite radar images, was used for the identification of unstable areas affected by surface movements [12]. Tan et al. [11] applied satellite radar interferometry to measure subgrade deformation in the test site along the Qinghai-Tibet railway in permafrost region. Bernhard et al. [13] estimated surface deformations along railway tracks in Northern Switzerland by conducting a Persistent Scatterer Interferometry (PSI) analysis utilizing time series of TerraSAR-X satellite observations. Satellite Synthetic Aperture Radar (SAR) data processing results for surface displacements for the railway line in Bulgaria proved to be reliable when compared and analysed with results from GNSS networks [14].

Transition zones in railway tracks are locations with considerable changes in the rail-supporting structure. Without timely maintenance, the differential settlement may lead to the damage of track components [15]. Interferometric Synthetic Aperture Radar (InSAR) technology is also widely used in this area, whose results show a good correlation with measurements obtained using a measuring coach and a Digital Image Correlation (DIC) device [15].

Many of the railway bridges built in the second half of previous century need to be rebuilt due to increased traffic loads, accumulated deterioration, and more stringent bridge design codes. Extreme weather conditions, such as temperature change, flooding, and wind loading, can also affect the structural health of railway bridges [16]. Zhu et al. [17] demonstrated the performance of the continuous monitoring of the foundation displacement in long-span bridges with GNSS technology. InSAR technology was also applied to railway bridges. It was used for 3D visualization and early warning of unexpected bridge displacements [18]. The same authors introduced the concept of displacement thermal sensitivity.

3. USED SATELLITE DATA, SATELLITES AND PROCESSING METHODS

The most broadly used satellite data are SAR data [2, 3, 5, 6, 11-15, 18]. SAR systems are able to measure the sensor to target distance by recording the time elapsed between the emission of the electromagnetic wave from the satellite towards the Earth's surface and the reception of the signal that is back-scattered by the ground itself [12].

The measurement of displacements on ground structures down to the millimetre level requires the processing of several radar images taken at different times using advanced techniques, such as interferometric SAR (InSAR) [2, 3, 5, 6, 11-15, 18].

The PSInSAR technique aims to detect radar targets on the Earth's surface identified by the satellite in that area that are characterised by a stable temporal electromagnetic response – Permanent Scatterers (PS) – which generally correspond to ground elements such as manufactured structures (including railway tracks) [6, 12].

TerraSAR-X radar satellites were most often used to obtain SAR data [2, 6, 13, 15], followed by RADARSAT-1 and RADARSAT-2 radar satellites [3, 12, 18], Sentinel-1 satellites [5, 14], and Envisat/ ASAR satellites [11].

The methods used to process SAR data vary from probabilistic method for InSAR time-series postprocessing [3], to method for PS geolocation improvement aided by Light Detection and Ranging (LiDAR) data [5], and method for deriving optimal data by analysing algorithms that account for the unique characteristics of railways traversing urban, farmland, and mountainous areas [6].

GNSS data are used not only for navigation in railways, but also for monitoring of railway infrastructure. Specht et al. [4] used GPS and GLONASS satellite data. They performed measurements using receivers installed on a moving rail vehicle. Zhu et al. [17] used GPS and BeiDou satellite data for monitoring displacement of railway cable bridges. The GNSS data were corrected by establishing non-linear mapping between the GNSS data and precise levelling data by back propagation neural network to improve the observation accuracy.

In the remaining studies, related to monitoring of vegetation and water level around the rail track, researchers used data from the QuickBird satellite [7], Sentinel-2 and Landsat 7 satellites [8], Pleiades satellites [9], and PlanetScope Dove satellites [10].

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STATIC TESTING OF BRAKE TRIANGLES OF RAILWAY VEHICLES

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Abstract *– Brake triangles are very important parts of the braking system of railway vehicles that can significantly affect safety and security on the railway. In accordance with the international standard UIC 833, the requirements for manufacturers of brake triangles are very strict and require the supplier to provide proof of the quality of the brake triangles. Therefore, manufacturers must provide appropriate evidence of the quality of production of brake triangles in accordance with the above-mentioned international standard. The paper presents the basic requirements of the international standard UIC 833 and the development of the test stand for static testing of brake triangles of railway vehicles in the Serbian company Tehnoliv Komerc from Velika Plana. This allowed this company to start a very successful mass production of brake triangles for the international market.*

Keywords – Static test; test stand; brake triangles; railway vehicles.

1. INTRODUCTION

The quality of braking is one of the most important prerequisites for adequate safety and security of railway traffic. The concept of braking of freight wagons is usually based on the friction between the brake shoes and the running surfaces of the wheels [1, 2]. Brake triangles play a very significant role in achieving that friction, i.e. realizing the braking force (Fig. 1).

Fig.1. Braking elements of freight wagon

As very important and responsible elements of the braking system, the brake triangles are subject to rigorous requirements prescribed by international standards. In order to ensure quality, every manufacturer of brake triangles for the international market must meet requirements of standards of International Union of Railways (UIC) [3, 4].

2. BASIC REQUIREMENTS OF INTERNATIONAL STANDARD UIC 833

Brake triangles should be made of carbon steel which geometric, physical, mechanical and chemical characteristics must meet all necessary requirements of ISO and EN standards. According to the UIC 833, brake triangles are classified into two groups: brake triangles for nominal load F_n=60 kN and brake triangles for nominal load F_n=120 kN. The relative positions of the functional parts of brake triangles such as trunnions, traction head and holes for the traction pin (Fig. 2), must be within certain prescribed limits.

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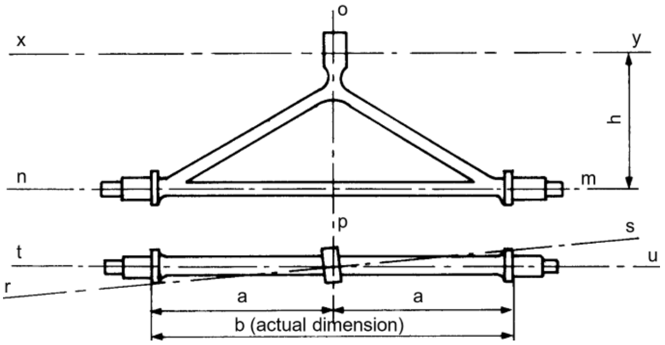

Fig.2. Relative positions of functional parts of brake triangles [3]

During the action of the nominal load F_n applied in accordance with the diagram shown in Fig. 3, the height *h* of the brake triangle must not have an elastic deflection greater than 2 mm. The values of loads for testing of brake triangles are given in Table 1.

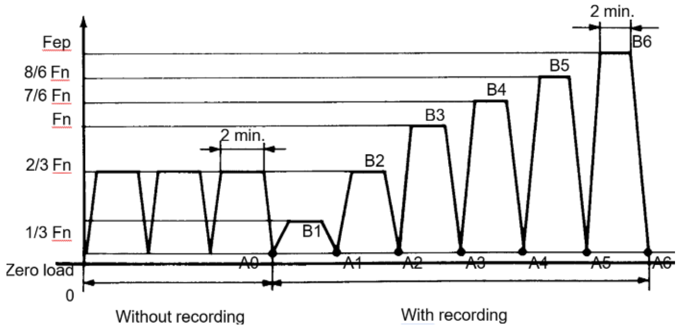

Fig.3. Load-time diagram for testing of brake triangles [3]

Tab. 1. Values of loads for testing of brake triangles

Type	"Zero" load	Nominal load F_n	Test load F_{ep}	Load variations during fatigue test
Tr. 60 kN	5 kN	60 kN	90 kN	10 kN to 60 kN
Tr. 120 kN	10 kN	120 kN	180 kN	20 kN to 120 kN

After the end of force action, the height *h* must not have a permanent deflection greater than 0.1 mm. Also, there must not be any other permanent deformations that can affect other parts of the brake triangle. During the action of the test load F_{ep} (9/6 of the nominal load F_n), applied in accordance with the diagram shown in Fig. 3, the height *h* of the brake triangle must not have an elastic deflection greater than 3 mm. After the end of force action, the same height must not have a permanent deflection greater than 0.5 mm. After testing, no defects must be present. Furthermore, the brake triangles must withstand 106 cycles of tensile loads applied at a frequency between 2 Hz and 16 Hz, without any apparent defects. These loads must vary cyclically within the limits specified in Table 1 [3, 4].

Consequently, manufacture of brake triangles can only be entrusted to suppliers who have appropriate approvals of purchasing Railways. The purchasing Railway must approve each prototype of the brake triangle and the conditions of its production. The authorized representative of the purchasing Railway performs an appropriate inspection of the production of brake triangles. He can perform all the checks he deems necessary to prove that all production conditions are satisfied. He may be present at welding operations and individual tensile tests conducted by the manufacturer. In addition, he must be informed about any change in the production process of the brake triangles. Regarding the acceptance inspection of the authorized representative of purchasing Railway, a batch of parts intended for the acceptance procedure must be provided. It consists of a minimum of 10 brake triangles produced by normal manufacturing methods. These brake triangles must not be exposed to a load greater than 2/3 of the nominal load F_n (Fig. 3, Table 1). Thus, brake triangles must be subjected to appropriate checks and tests specified in UIC 833 [3]. They are performed either at the time of receipt during delivery or during production. The tests prescribed by the acceptance program must be carried out by a laboratory approved by the purchasing Railway. The brake triangles must be submitted for acceptance in the delivery condition, before any protective treatment. Previously, they must be subjected to static deflection tests in accordance with the details specified in UIC 833.

3. TEST STAND FOR STATIC TESTING OF BRAKE TRIANGLES

With the aim of conquering the production of brake triangles in accordance with the requirements of the UIC 833 standard, a special test stand for static tests of brake triangles was developed in company Tehnoliv Komerc from Velika Plana, Serbia (Figs. 4 and 5). The test stand enables fast and simple mounting of the tested brake triangles and setting the load [5].

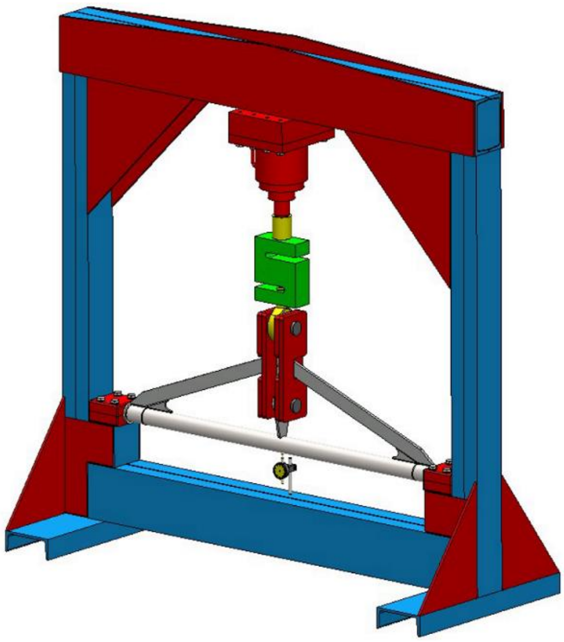

Fig.4. Model of developed test stand

Fig.5. Test stand in operation (company Tehnoliv Komerc)

The test stand is made as a robust spatial frame construction within which the load flow is "closed". The material of the supporting structure of the test stand is structural steel S355. The strength of the test stand is calculated using the finite element method (FEM) (Fig. 6). The calculation results show that the supporting structure of the test stand meets the strength criteria, while the stresses and deformations are within the permissible limits (Figs. 7 and 8).

The load setting system is based on a hydraulic cylinder with manual control (Fig. 5). The measuring system for registering and recording the value of the applied force is based on the force transducer type ZEMIC - H3-C3-30t-6B (Figs. 5 and 9).

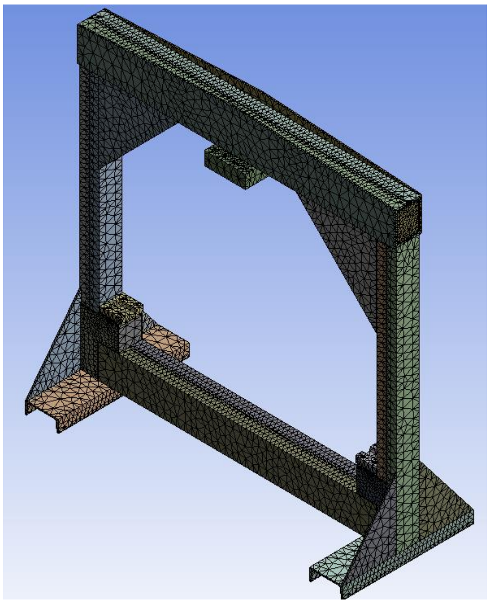

Fig.6. Discretized model of test stand structure (122908 nodes and 54594 finite elements)

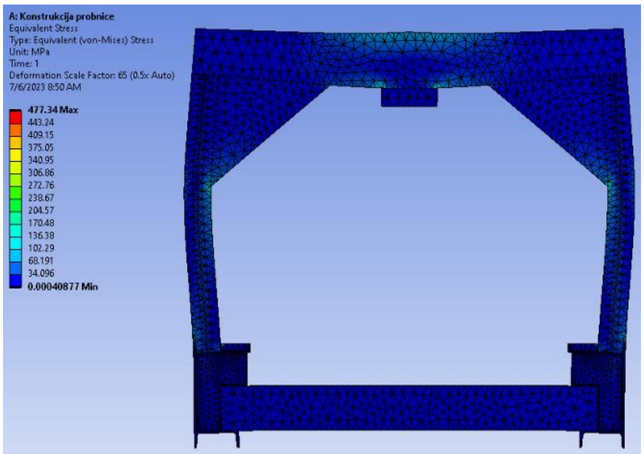

Fig.7. Equivalent stress of test stand structure

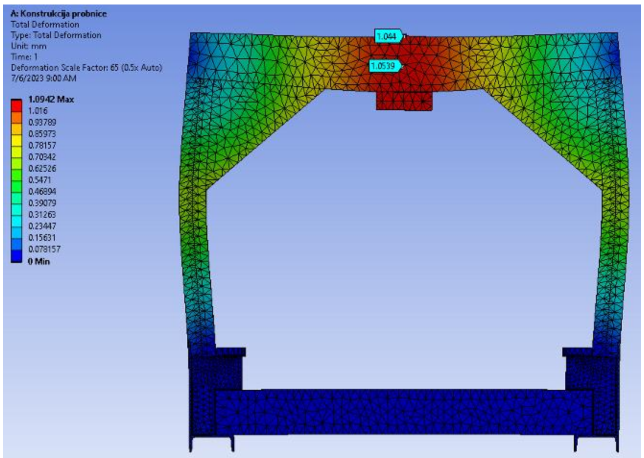

Fig.8. Total deformation of test stand structure

Fig.9. Force transducer with data acquisition system

The developed test stand has a vertical movement and allows maintaining a constant load for at least 2 minutes, while this load is measured with an error of less than 1%. The deflections are measured with rigidly fixed dial gauges with graduation of 0.01 mm.

Before conducting the static tests, three consecutive preliminary loads of 2 min duration and equivalent to 2/3 of the normal load F_n specified in Table 1 are applied. After that, the force returns to the "zero" load which is also listed in Table 1. These procedures are performed without recording deflection values.

After that, loads equal to 1/3 F_n, 2/3 F_n, F_n, 7/6 F_n, 8/6 F_n and 9/6 F_n are then applied, in turn, for two minutes each. The application of each new load is preceded by a return to the load that must not be less than the mentioned "zero" load specified in Table 1. The deflection values reading from dial gauges is performed for each of the "zero" loads and under each of the above mentioned loads, i.e. in the points A0, B1, A1, B2, A2, B3, A3, B4, A4, B5, A5, B6 and A6 (Fig. 3).

During the described test, the following deflections are measured:

- Elastic deflection under the nominal load F_n (equal to the difference in measurement results in points B3 and A3);
- Permanent deflection under the nominal load F_n (equal to the difference in measurement results in points A3 and A0);
- Elastic deflection under the test load F_{ep} (equal to the difference in measurement results in points B6 and A6);
- Permanent deflection under the test load F_{ep} (equal to the difference in measurement results in points A6 and A0);
- Any permanent deflection, other than that obtained in the direction in which tension was applied (determined by comparing the measurements performed to the nearest 0.1 mm by reference to a surface-plate, before and after the tensile test).

Therefore, the developed test stand fully meets the requirements of the UIC 833 standard for static testing of brake triangles of railway vehicles.

4. RESULTS AND CONCLUSION

The paper presents the cooperation between the company Tehnoliv Komerc from Velika Plana and the Faculty of Mechanical and Civil Engineering in Kraljevo in the field of conquest the production of brake triangles of railway vehicles and the design and development of test stand for static tests of brake triangles. It provided Tehnoliv Komerc mass production of brake triangles for the international market (Fig. 10). So far, more than 3500 brake triangles have been successfully manufactured and delivered.

Fig.10. Detail from brake triangles production (company Tehnoliv Komerc, Velika Plana, Serbia)

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RESEARCH OF THE DRAW HOOK FAILURES ON RAIL VEHICLES IN SERBIA

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Abstract *– Draw hook failures present significant problems for railway safety and operational efficiency. Although failures on the draw gear are not frequent, they can induce serious problems on the vehicles and infrastructure when some elements break. This paper presents comprehensive research on the potential causes of these failures, aiming to provide insights for prevention measures related to materials, production process, geometry and manipulation practices during train operation. The draw hook, as one of the vital components in connections of wagons and locomotives, ensures the safety and reliability of trains during operation. By analyzing the historical failure data and relevant literature, this study identifies several key factors contributing to coupler failures. Material degradation emerges as a prominent concern, with factors such as fatigue, wear, and corrosion compromising the structural integrity of the coupler hook and other components over time. Overloading during starting, impacts, or improper coupling procedures further increase the risk of failures. Mechanical and physical characteristics of used material, as well as geometric inconsistencies, may also induce failure under operational conditions. Environmental factors, such as extreme temperatures, moisture ingress, and chemical exposure, pose additional challenges by accelerating material degradation and corrosion processes. Understanding the complex interaction of these factors is crucial for developing effective preventive maintenance strategies and for addressing and improving observed imperfections in draw gear elements. Implementing the results from this research can help railway operators and manufacturers of subjected elements mitigate the risk of failures, thereby ensuring the continued reliability and safety of rail transportation systems.*

Keywords – draw hook, failure, maintenance, rolling stock, rail vehicles.

1. INTRODUCTION

Rail transport has a crucial role in Serbia's economy, connecting major cities and facilitating the movement of goods and passengers. The efficiency and safety of rail operations depend on the proper functioning of each component of rail vehicles. Disruption in freight transport due to breaking some part of the draw gear assembly is one of the main reasons for excluding trains from traffic and delivery delays. The draw hook, as a main part, is essential for the secure connection between railcars, ensuring safe and reliable transportation.

Despite the importance of draw hooks, instances of failures have been observed in rail vehicles across Serbia (at the national and international trains), raising concerns about safety, reliability, and potential operational disruptions. These failures not only pose risks to the safety of passengers, goods, and personnel, but also bring significant economic costs and logistical challenges when vehicles or trains must be excluded from traffic.

Understanding the root causes of draw hook failures represents the key in lowering risks and enhancing the overall safety and efficiency of rail transportation systems in Serbia. Various factors such as material

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quality, design, maintenance practices, and operational conditions may contribute to these failures and warrant thorough investigation.

This paper aims to comprehensively present a few failures of draw hook and a preliminary analysis of the causes of failures on rail vehicles in Serbia. Analysis of the available data on the draw hook failure will indicate the potential problems that lead to them.

Analysis of the fatigue failure of draw hooks and identified the key factors contributing to this issue were presented in paper [1]. Results of these investigations showed that the draw hook fatigue failure resulted from the combined effect of three main factors: the material, manufacturing technology, and operating conditions. Investigation of the causes of a locomotive draw hook brittle failure pointed out that the fracture was due to the inadequate impact toughness of the used material [2]. The brittle fracture of the locomotive draw hook caused by the unsuitable material characteristics of the draw hook itself, and non-coaxial loading conditions during operation presented in paper [3] once again confirming the causes described in paper [1]. Study on the draw hook equipment fatigue life utilized in freight wagons was presented in paper [4]. This study explored fatigue in the draw hook body, examining various metallurgical and mechanical properties that impact fatigue through experimental and numerical methods. Although the draw gear assembly is designed with weaker elements, such as the coupling links, whose fractures are analyzed in the papers [5, 6], draw hook failures occasionally occur. The analysis of these failures is complex experimental work that is focused on mechanical and metallographic examination of the material, as well aa micro and macro analysis of the structure of the material. In this paper are presented examples of draw hook failures and the preparation for analysis of failures (breakages) of draw hooks in Serbia, through experimental research.

2. DRAW GEAR ASSEMBLY

Draw gear assembly is formed from mechanical parts in a line with an energy absorber-elastic device mounted in the end beam on the railway vehicle, which works during operation, traction and braking, Figure 1. The draw gear assembly must have robust construction and be adequately sprung to minimize the impact loads from the starting jerks. Three characteristic breaking sections are presented in Fig 1. and will be explained in Subtitle 3.

2.1 Draw hook dimensions - EN 15566

Standard dimensions of draw hook which represents a part of draw gear assembly is shown in Figure 2.

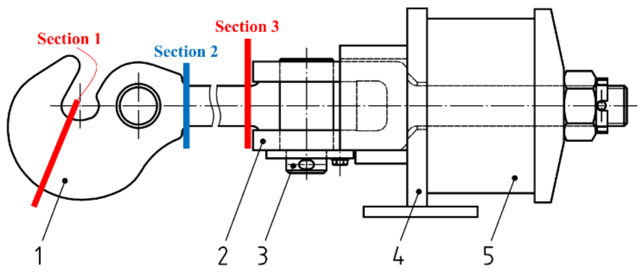

Fig. 1. Draw gear components: 1 - draw hook; 2 - drawbar; 3 - joint pin; 4 - support plate and 5 - elastic device [7]

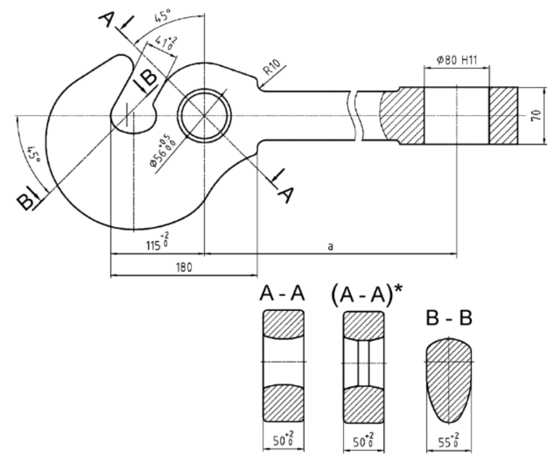

Fig. 2. Draw hook [7]

3. ANALYSIS OF DRAW HOOK FAILURE

The aim of this paper is to show and identify some of draw hooks failure on rail vehicles in Serbia, as well as to present method for determine causes that contribute to these failures. Surface of the broken locomotive draw hook (Section 3, Fig. 1) happened in 2020. in Serbia is presented in Figure 3 [8].

Fig. 3. Locomotive draw hook

Two more broken hooks in Serbia were presented in Figures 4 and 5. The first draw hook broke in March 2021. on the line Belgrade-Novi Sad, Figure 4. The place of break fits Section 2 in Figure 1. The draw hook was a part of the draw gear of one of 29 freight wagons in the train with a gross weight of 1920t and a total length of 479 m.

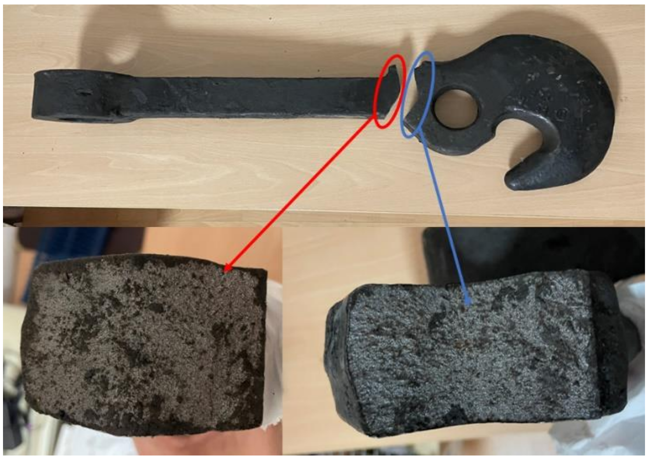

Fig. 4. Draw hook 1

The second draw hook accident happened in July 2021, Figure 5. This accident occurred when the train of mass 1662t was accelerating from 20 km/h to 30 km/h on an incline. Reaching the speed of 30 km/h, the train was stopped due to a loss of air from the main brake line. The place of the break fits Section 1 in Figure 1.

Fig. 5. Draw hook 2

The experimental investigations of the failures of these two draw hooks will focus on the analysis of the material properties and the operational conditions.

Next to the analysis of material properties and micro and macrostructure of the broken draw hooks, additional tests, and analysis will be conducted of the new draw hooks (unused). Results and characteristic parameters obtained by tests of broken and new draw hooks will be compared. Also, these experimental results will be used for the development and validation of the numerical model. A 3D model of draw gear assembly will be formed in the software package SolidWorks, while the development of the numerical model and finite element analysis (FEA) will be done by using the ANSYS software package. The FEA will be employed to simulate load distributions, stress analysis and uncover the potential failure points. This comprehensive approach will provide a detailed understanding of the factors leading to draw hook failures.

Tensile tests will be conducted on failed and new draw hooks to measure their mechanical and physical characteristics and chemical composition, providing insights into the material's performance under load. Also, the Charpy impact test will be conducted on different temperatures to analyze the impact of low or high temperatures on the material properties and toughness. The testing samples will be prepared according to standard [7]. Figure 6 shows the exactly defined positions on the hook for cutting samples.

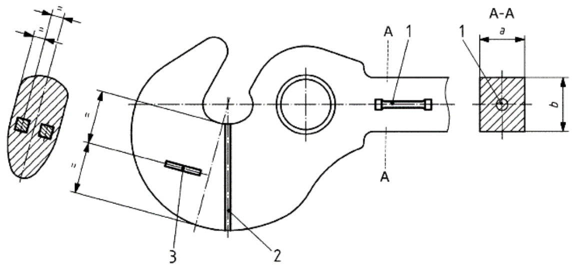

Fig. 6. Draw hook tensile position: 1 - tensile test sample normalized; 2 - macrographic and micrographic examination sample and 3 - impact test sample [7]

In addition, to the mentioned tests, hardness tests of the material will be performed to get the useful parameters for evaluation. The plan is to carry out fatigue tests to assess the endurance limit and fatigue life of the draw hooks under cyclic loading conditions. These mechanical tests are crucial for understanding the properties contributing to draw hook failures and will inform the development of more robust designs. Material characterization will involve analyzing the chemical composition of the draw hook material using techniques such as optical emission spectroscopy (OES) to detect any deviations in alloy composition that might affect performance. Additionally, the microstructure of the material will be examined using optical microscopy to identify defects such as inclusions, voids, or grain boundary issues that could contribute to failure. These analyses will provide a comprehensive understanding of the material properties and potential factors leading to draw hook failures. A developed and validated numerical model will be used for different analyses of draw hooks with a significant reduction in research costs. In this way easily change the material properties and geometry of the draw hook and analyze their impact on strength and operational reliability. Also, experimental and numerical research will be useful for improving production processes and maintenance and reducing their costs.

4. CONCLUSION

This paper aims to lay the groundwork for research on the causes of draw hook failures on rail vehicles in Serbia, critical components ensuring the safe and efficient operation of rail transport.

Experimental and numerical research will provide a comprehensive understanding of the causes that contribute to drawing hook failures in Serbian rail vehicles. Analysis of key factors, it is possible to improve the safety, reliability, and efficiency of rail transportation systems in Serbia, ultimately reducing risks and operational disruptions.

The developed and validated numerical models will present a base for significantly more extensive research and analysis with low investigation costs.

Future research should explore advanced materials and innovative design solutions to further enhance the performance of draw hooks and other critical rail vehicle components.

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INFLUENCE OF VEHICLE LAYOUTS ON CAPACITY AND ENERGY CONSUMPTION

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Abstract *– In order to meet growing demand and environmental policy requirements, it is important for local rail passenger transport to increase its performance. There are various options for this in the area of infrastructure. At the same time, the layout of the vehicles also has a significant influence on performance. Incorrectly planned vehicles lead on the one hand to a significant reduction in the capacity that can actually be achieved and on the other hand to an unnecessary increase in passenger changeover times. The longer passenger changeover time also means a longer train sequence time and therefore a reduction in performance on the line.The presentation shows which errors in the planning of night trains (underground trains, suburban trains, regional trains) lead to a reduction in efficiency as a result of the passenger changeover time and, conversely, which measures in the vehicles help to increase the efficiency of a line or network. At the same time, there is potential for energy savings.*

Keywords – public transport efficiency, capacity, dwell time, energy efficiency.

1. INTRODUCTION

To have a positive influence on operational efficiency by the vehicle layout, the behaviour of the passengers who will use the vehicle must be placed at the centre of all considerations when designing rail vehicles. If the requirements and expectations of the passengers are not sufficiently taken into account, such as the different current realities of life and travel conditions, such as the purpose of the journey and the activities derived from it, the luggage taken along, fellow travellers (e.g. children) or any mobility restrictions, the resulting inadequately designed interior of the vehicles often leads to noticeable inefficiency.

2. METHOD

All of the following findings are based on more than twenty years of research and implementation of around 40 research and consultancy projects, in which observations on trains from over 400,000 passengers, video time measurements of boarding passengers and our own series of tests in the vehicles and interviews with travellers were used to gather information, such as which seats are preferred, where and how luggage is stored, what difficulties arise when storing luggage or boarding and moving around in the vehicle. It was possible to comprehensively survey behaviour in relation to taking and storing luggage. Based on this extensive data, which exclusively takes into account the specific behaviour of passengers on trains, the software TrainOptimizer® was developed in cooperation with the Vienna University of Technology and netwiss, with the help of which vehicle layouts can be very easily assessed in terms of their efficiency by means of simulation. The findings presented in this paper are based in part on the use of simulations in TrainOptimizer®. Fig.1 shows the symbolic simulation flow chart. In a first step, layouts are created in an easy-to-use editor and then further settings such as deviating age distribution, special journey purpose mixes, region-specific data etc. are selected for the evaluation if required. Based on the extensive data available, the tool knows the luggage volume and the behaviour of travellers when boarding and disembarking and in the context of luggage accommodation. The output is easy-to-understand graphics on passenger changeover times, luggage stowage and seat usability..

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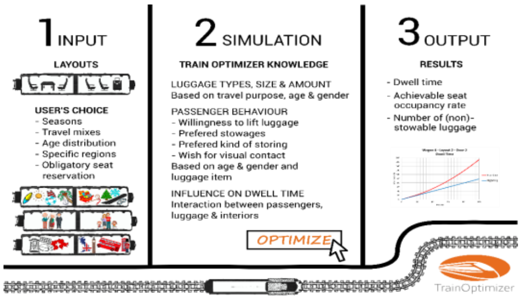

Fig.1. Simulation flowchart with TrainOptimizer®

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3. PASSENGER BEHAVIOUR IN RELATION TO THE LAYOUT

Relevant passenger behaviour with a significant influence on efficiency in long-distance transport results in particular from the carriage of luggage. This influences behaviour when boarding and moving around the vehicle, when looking for a seat and when storing luggage. Sufficiently dimensioned luggage racks are essential and must meet the following two basic requirements of travellers:

- Travellers want to avoid lifting heavy luggage in particular
- For reasons of subjective safety, travellers want to have visual contact with their own luggage at all times

In local transport in particular, in addition to person-specific influences such as age or any mobility restrictions, the fact that people want to be able to reach the exit at any time and therefore avoid "unpopular" areas in the vehicles from which this is supposedly not possible is also decisive. This leads to irregular utilisation of the vehicle and thus to reductions in the de facto vehicle capacity with equally negative effects on the passenger changeover time.

There must be good passenger flow inside the vehicle. The aisle width, the distance between the seats, the accessibility of the seats or, conversely, a high proportion of hard-to-reach seats, the presence or absence of luggage racks have a significant influence on the flow of passengers inside the vehicle. Unfavourably designed interiors quickly result in a backlog, for example when a person wants to get to a free window seat (see Fig 2).

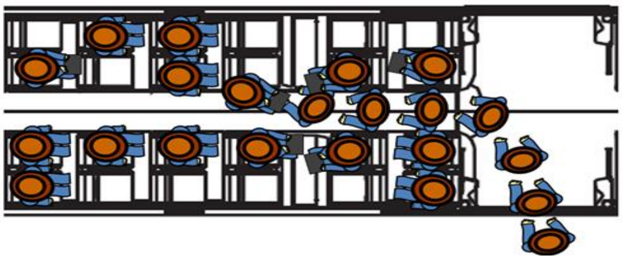

Fig.2. Backlog due to a cramped interior

In both long-distance and local transport vehicles, the arrangement and size of the doors also has a significant influence on the passenger changeover time. If a division of the passenger flow can be achieved after boarding a vehicle, the passenger changeover time is significantly accelerated. In addition, the door width should be at least 90cm for long-distance trains and at least 160cm for local trains in order to further speed up the passenger changeover. As a rule, door widths up to approx. 140cm barely allow two parallel walking lanes, while doors from 160cm have the full boarding capacity of two single doors.

Other noticeable influences on the passenger changeover time are the number of boarding steps and the passenger flow in the interior. A level boarding with gap bridging represents the ideal situation here; a gap extends the passenger changeover time by 1/10 sec per person. If, on the other hand, there is one or more steps, the passenger changeover time can be multiplied, especially in combination with luggage transport. An "open" area, e.g. in the form of a small multi-purpose compartment, should be provided on both sides of the boarding area (if the door arrangement allows passenger flow in both directions) for passenger flow in the interior. The adjoining aisles should have an aisle width of at least 60 cm.

Doors arranged in such a way that the flow of passengers can split into two directions after boarding have a very positive effect. A possible backlog from inside the vehicle (see Fig.2) can thus be reduced because the boarding passengers have two routes available and then continue in the direction in which the backlog takes less time (see Fig.).

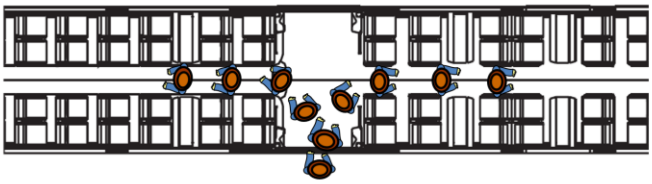

Fig.3. Division of the passenger flow

As mentioned earlier, doors with a width of 160cm or more significantly help to reduce the passenger changeover time. Whereas with doors up to 140cm the majority of passengers board one behind the other or offset to each other, with a door width of 160cm most passengers board the vehicle side by side, resulting in two walking lanes (see Fig.4). The time required for boarding per person is reduced from 1.3 seconds to 0.75 seconds. However, if the vehicle interior is cramped (as in Fig.4), then splitting the passenger flow does not help, as the backlog from the interior immediately builds up to the door.

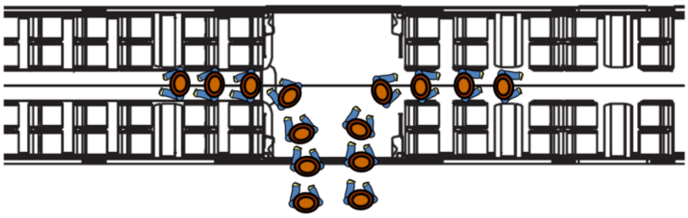

Fig.4. Division of the passenger flow - door width min. 160cm - two walking lanes

In order to achieve the time advantage of the wide doors, the doors must therefore be 160cm wide, there must be a standback area of at least 25cm to the left and right of the door and the interior must allow passengers to flow away easily on both sides (see Fig. 6).

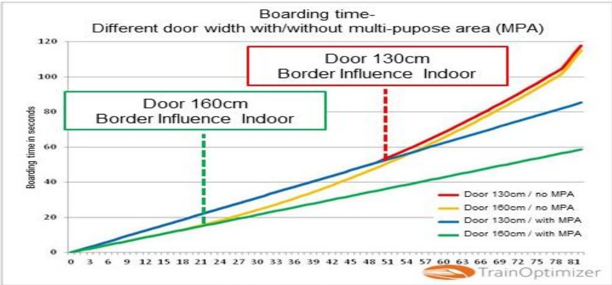

Fig.5. Boarding time, different doors and interiors

Fig.5 shows the time required for boarding, once with a door width of 130cm and once with 160cm. In both cases, there is a cramped interior space without a multi-purpose area and with a multi-purpose area on both sides, which accelerates the passenger flow (see Fig.6). It can be seen that the passenger changeover is very fast with a door width of 160cm. However, if the interior is cramped, the passenger changeover time starts to increase due to the backlog despite the wide door. However, if the door is only 130cm wide, it is the bottleneck, no matter how well the passenger flow inside the vehicle works.

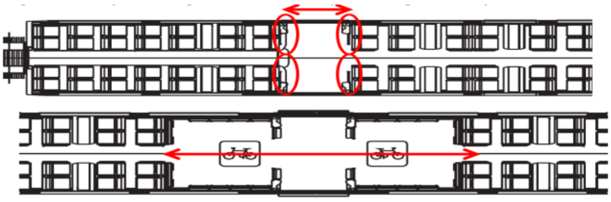

Fig.6. "Narrow" entrance vs. "wide" entrance

The free areas next to the doors also serve as multi-purpose areas for baby prams, wheelchairs, bicycles, luggage, etc., significantly speeds up the flow of passengers and increases capacity. Particularly with regard to capacity, it is important to ensure that there are as few "unpopular seats" as possible. Passengers want to get from their seat to the exit quickly, especially if there are a lot of passengers on the train. In those areas from which the exit is not easy to reach at peak times, there are fewer people, which reduces the capacity utilisation and thus the de facto capacity. Fig.7 shows an example vehicle. The red areas indicate low occupancy. These are mainly seats with a large distance to the door.

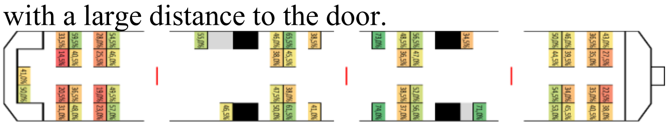

Fig.7. Accessibility of various areas

In order to increase capacity and distribute passengers in the vehicle as evenly as possible, it is generally important to enlarge the boarding area and ensure that all seats have good accessibility to the door. One way of doing this is shown in Fig.8.

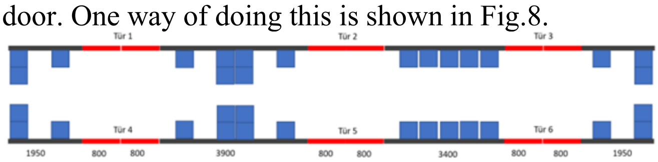

Fig.8.Efficient metro layout

With this layout, not only a high capacity is to be expected, but also a very fast passenger changeover.

4. EFFECTS ON CAPACITY AND PERFORMANCE

The most important effects of the vehicle layout on capacity in terms of seats and, in local transport, standing room per train and performance as a measure of the number of trains per hour and thus the number of passengers per hour are shown below:

1) Vehicle layouts that include many "unpopular" areas in local transport and do not take sufficient account of the basic requirements for luggage storage, especially in long-distance transport, lead to a lower possible de facto utilisation per wagon and thus per train.

2) If the dwell time is extended as a result of the above-mentioned reasons, this leads to increased train running times with a corresponding reduction in performance, especially in local transport.

Conversely, an increase in capacity and performance can be achieved if

1) Sufficiently dimensioned luggage storage facilities that meet passenger requirements are available, especially in long-distance transport. The actual seat availability can be increased by up to 20%.

2) There are no "unpopular" areas. In local transport in particular, these are areas with a longer route to the exit, where passengers are concerned that they will not be able to board the train in time.

3) layout measures that contribute to a reduction in dwell times and generally use vehicles with a high acceleration capacity. As a result, the train headway can be reduced, especially in local transport, and the number of trains per hour can be increased, taking into account other necessary infrastructure measures. For example, the stopping time on local services can be reduced by up to 20 seconds, which means a corresponding reduction in the train sequence and higher capacity.

In addition to the vehicle layout considerations, it is also important to carefully weigh up the general vehicle concepts in order to increase capacity. In particular, the use of double-decker trains and, ideally in combination, multiple-unit trains will lead to a further increase in train capacity.

5. EFFECTS ON RAILWAY OPERATIONS, INVESTMENT MEASURES AND ENERGY REQUIREMENTS

The stopping time has an impact on railway operations on several levels. In order to increase efficiency, measures must be sought to help minimise stopping times. The vehicle layout has a significant influence on this, and in addition the technically required times for door release and door closing must be reduced and the operational handling procedure optimised.

The most important positive effects of a minimised holding time are

1) Punctuality: The quality of service suffers when stopping times are extended, whereas minimised stopping times make a significant contribution to keeping to the timetable and therefore to punctuality. By reducing the stopping time, the buffer time is increased while the total journey time remains the same.

2) Edge journey times: The edge journey times are made up of half the dwell times in the neighbouring nodes and the journey time between the two nodes and are an essential feature of a synchronised timetable. As the edge journey time has a constant value (integer multiple of half the cycle time), a longer dwell time automatically requires a shorter journey time between the two nodes, which can only be achieved by a higher travelling speed. Conversely, the minimised dwell time in the stations can also reduce the travel speed. This has the following effects:

a) Energy saving: The lower travelling speed saves energy. There is further potential for energy savings and the associated reduction in operating costs in the area of structural weight. Vehicles with long car bodies and two bogies each have a higher total weight than articulated train concepts with Jacob's bogies or even single wheels. Such concepts allow the total weight of the train per seat to be further reduced, which leads to a corresponding reduction in energy requirements.

b) Infrastructure expansions: The infrastructure is often adapted and expanded in order to achieve the journey time required to reach the edge journey times. If journey time reductions in the range of minutes are required to achieve the edge journey time, then these time gains can be achieved by reducing the dwell time, which may eliminate the need for expensive infrastructure measures.

c) Vehicle savings: For various rotations, especially in the area of local transport, a reduction in dwell time, especially with many intermediate stops, can lead to a reduction in the total journey time, which means that there is potential to save one or more vehicles in the entire rotation while maintaining the same service

6. CONCLUSION

The dwell time is an important lever for increasing operational efficiency. Shorter dwell times in a synchronised timetable mean lower required travel speeds with the corresponding potential for energy savings, higher travel time reserves and thus improved punctuality and, conversely, offer the possibility of reducing the travel time to achieve the required edge travel times and help to avoid potentially expensive infrastructure expansions.

In order to reduce the dwell time to generate the above-mentioned benefits, the following factors must be taken into account:

1) Sufficient and properly designed luggage racks

2) Avoid unpopular areas, especially in local transport vehicles

3) The door arrangements must be selected in such a way that the passenger flow can be divided after boarding.

4) There should be as few steps as possible, ideally a level boarding with gap bridging

5) Door widths must be at least 90cm for long-distance transport and at least 160cm for local transport

6) After the boarding area, good passenger flow must be ensured, with aisle widths of at least 60 cm and open areas such as multi-purpose compartments at the beginning of the aisle.

7) Vehicle concepts such as double-decker trains, multiple-unit trains and trains with shorter car bodies and Jacob's bogies or single wheels lead to a reduction in structural weight per passenger with corresponding energy efficiency. Such vehicles also largely increase capacity.

If the above-mentioned design rules for rail vehicles are fully taken into account from the outset, the efficiency of the railway system can be significantly increased without additional expense, as an increase in capacity, lower energy requirements, higher punctuality and possibly the avoidance of more expensive line extensions can be achievedThe chapter Conclusion which summarizes the paper is obligatory.

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IN-SERVICE ASSESSMENT OF EQUIVALENT CONICITY WITH THE AIM OF PREVENTING THE UNSTABLE RIDE OF RAIL VEHICLES

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Abstract – *The paper provides a general survey of methods for equivalent conicity assessment. Different aspects of interest are addressed: type tests of new rail vehicles, acceptance of new railway tracks, as well as vehicles and infrastructure in-service. The paper discusses the procedure if the ride instability appears in service. According to European legislation, this situation requires equivalent conicity assessment on vehicle and infrastructure. The procedure is demonstrated for one vehicle in service, combined with reference rail profiles and rail profile samples acquired by track recording vehicle at the new Belgrade-Novi Sad railway line for 200 km/h, in combination with reference wheel profiles.*

Keywords* – *equivalent conicity, assessment methods, ride stability, in-service assessment, rail vehicles, rail infrastructure.

1. INTRODUCTION

Even before the birth of the railways the experience with mining wagons led to usage of conned wheels on wheelsets. Compared to cylindrical wheel profiles this resulted in lower curve resistance and lower wheel wear. Half a century of railway history passed before Klingel, in 1883, derived formula for sinusoidal motion of a free wheelset with conned wheels.

Vehicle wheelsets show stable ride up to some "critical speed" depending on connection characteristics and wheel-rail geometry. The wheel-rail geometry in service is influenced by wear. Therefore, equivalent conicity is recognized nowadays in European legislation [1,2] and standards [3,4] as a parameter which should be controlled in the design phase and in service of rail system.

2. WHEEL-RAIL CONTACT GEOMETRY

Conned wheels allow the wheelset to move in curves toward the outer rail by y, as presented in Fig. 1. The outer wheel then rolls at radius $r_2>r_o$, and

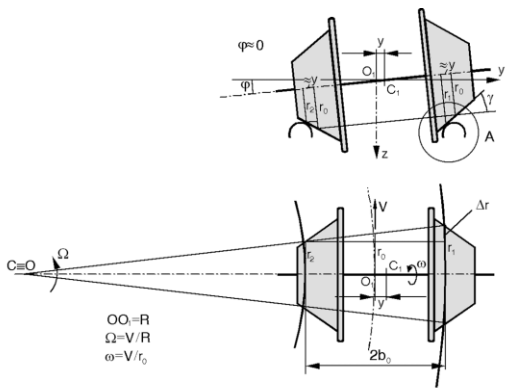

Fig. 1. Theoretical position of the wheelset with conned wheels in curve [5]

inner wheel at radius $r_2<r_o$. The difference:

$$\Delta r = r_1 - r_2 = 2n \cdot y \qquad (1)$$

allows the wheelset to pass the curve by pure rolling up to the maximum available lateral play of the wheelset in the track, i.e.:

$$y \leq \frac{TG\text{-}SR}{2} \qquad (2)$$

Here is:

γ - cone angle of wheel profile (fig. 1, 3)
n=tanγ - slope of the conned wheel profile
TG - track gauge

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SR - distance between active faces of wheel flanges (measured 10 mm below the nominal circle)

When the wheelset with conned wheel profiles is positioned laterally by y_o, at straight track (Fig. 2), its kinematic rolling, without slip in contact with rails produce so called hunting motion with center of wheelset describing sinusoid. Klingel’s solution of such motion gives wavelength of sinusoid:

$$L = 2\pi\sqrt{\frac{b_o \cdot r_o}{n}} \quad (3)$$

Here is:
$2b_o$ - lateral distance of nominal wheel diameters
r_o - nominal wheel radius

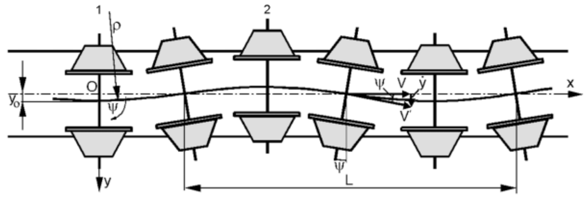

Fig. 2. Hunting motion of the wheelset

From formula (3) follows that if the wheel profile is cylindrical, n=0, $L \Rightarrow \infty$, and there is no sinusoidal motion. But cylindrical wheel profile gives no ability to pass a curve with pure rolling as presented in Fig. 1. Guiding of the wheelset is then performed only by forces on wheel flange, with presence of high resistance and intensive wheel flange wear.

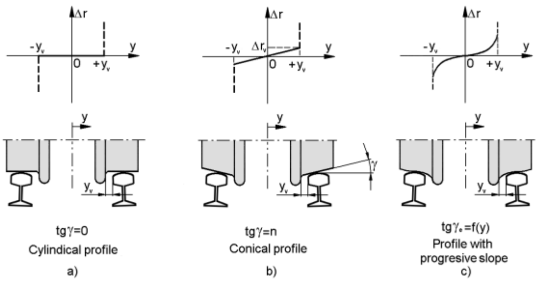

Fig. 3. Δr function of different profiles [5]

Equation (1) is so called Δr function which is for conned wheel profile linear (Eq. 1), up to the limit given by equation (2), Fig. 3b. Fig. 3a shows the Δr function of the cylindrical wheel.

As a compromise, profiles with progressive slope of Δr function (Fig. 3c) are preferred. The goal is to have the slope of the Δr function around center position of the wheelset (y=0) near zero, like with cylindrical wheel profiles, which is preposition for stable ride on straight track. In the curves Δr shall progressively rise, what is favorable for curving performances.

While in case of cylindrical or conical profiles Δr function does not depend on the rail head profile, in case of nonlinear profiles, both, wheel and rail profiles are influencing. Therefore, there is no ideal wheel profile. Real combinations of wheel and rail profiles in service usually have nonlinearities in form of jumps in Δr function which denotes two-point wheel rail contact, as well as asymmetry.

2.1 Equivalent conicity calculation

Equivalent conicity $\tan\gamma_e$ is defined as the cone angle of a wheelset with coned wheels whose lateral motion on straight track has the same kinematic wavelength as the given wheelset. This parameter is the main indication for the hunting motion of the wheelsets.

Determination of equivalent conicity is based on known wheel and rail profiles. In service conditions, this requires devices for profile measuring, based on optical or mechanical principles. For the calculation of the wheel-rail contact geometry, specialized software is required, which includes the calculation of the Δr function.

Starting from Δr function, in [3] are defined four methods for determination of wheel-rail contact parameters including equivalent conicity. In this paper, linear regression of the Δr function was applied.

Real wheel profiles were recorded using the device PGS2, which represents improvement of the PGS device developed for [6], Fig. 4. Recording of the rail profiles was performed using the measuring devices installed on the track recording vehicle „SEVER”. For the calculations software EQ, enhancement of the GED software developed for [6], is used.

Fig. 4. Wheel profile recording

Processing of the recorded profiles includes removal of spikes, averaging, smoothing etc. Checking of all measured profiles after a processing was necessary to avoid artificial distortion of profiles.

Linear regression of the Δr function gives the approximation of the equivalent conicity as:

$$\tan\gamma_e(\hat{y}) = B/2$$

where B is the slope of the regression line, $\hat{y}$ -amplitude of kinematic wheelset motion.

Generally, non-symmetric wheel and rail profiles in service cause the mid position of wheelset motion to differ from y=0, and amplitudes on left and right are different. Fig. 5 shows such an example of Δr function obtained using real wheel and rail profiles recorded in-service.

It is necessary to calculate asymmetric amplitudes for given amplitude span $2\hat{y}$, which makes the limits for linear regression interval. For that purpose, it can be started from the following form of Klingel’s equation:

$$\psi \cdot d\psi = \frac{-1}{2b_o r_o}\Delta r(y)\cdot dy$$

Integration of the equation results in:

$$(\psi_2^2 - \psi_1^2) = \frac{-1}{2b_o r_o}\int_{y_1}^{y_2}\Delta r(y)\cdot dy$$

When we chose a half wave between two peak positions, denoted as 1 and 2 in Fig. 2, it means $\psi_1=\psi_2=0$, $y_1=y_{emin}$, $y_2=y_{emax}$ and consequently:

$$\int_{y_{emin}}^{y_{emax}}\Delta r dy = 0$$

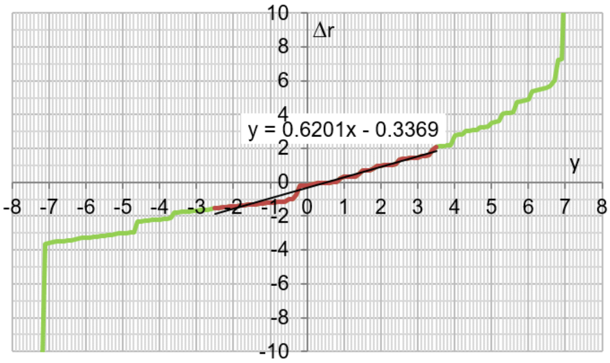

Fig. 5. Example of a Δr function in service

This integral can be calculated over complete range of y. For the Δr function given in Fig. 5 the integral value is shown in Fig. 6. Starting from the integral value at y_{emin} we need to identify second $y=y_{emax}$ with the same value of the integral. In that way it is possible to find limits for each desired double amplitude value $2\hat{y}=y_{emin}+y_{emax}$.

Fig. 6. Δrdy integral

For example, for amplitude $\hat{y}$=3 mm, in Fig. 6 are determined y_{emin}=-2.5 mm and y_{emax}=3.5 mm. These values are limits for linear regression in Fig. 5, from which can be obtained:

$\tan\gamma_e(\hat{y}=3)$ = B/2=0.620/2=0.31

In the same way values of equivalent conicity are calculated for the whole interval of amplitudes of interest, usually for $\hat{y}$ = 1 to 7 mm.

3. EQUIVALENT CONICITY REQUIREMENTS

There are different requirements for equivalent conicity. According to [4], for the acceptance of new types of rail vehicles the stability tests with speed $1{,}1\cdot V_{max}$ at test sections of 100 m length, with following minimum average equivalent conicity are necessary:

- for $v \le 120$ km/h: $\tan\gamma_e \ge 0.40$
- for 120 km/h < $v \le$ 300 km/h: $\tan\gamma_e \ge$ 0.534 - V/900) (rounded to two decimal digits)
- for v > 300 km/h: $\tan\gamma_e \ge 0.0$

Equivalent conicity should be calculated with real wheel and rail profiles used in test. For new track sections upper limits of equivalent conicity are given in Table 1 [1]:

Tab. 1. Infrastructure, design limits for $\tan\gamma_e$

	Wheel profile
Speed range [km/h]	S1002, GV1/40, SR=1420 and 1426 mm
$v \le 60$	Assessment not required
$60 < v \le 200$	0.25
$200 < v \le 280$	0.20
$v > 280$	0.10

If instability arises in service, according to [2], the railway undertaking shall measure the wheel profiles of the vehicle and the distance of active faces of the wheelsets. The equivalent conicity shall be calculated using the scenarios provided in Table 2 to check if compliance with the maximum equivalent conicity the vehicle was designed and tested is met. If this is not the case, the wheel profiles have to be machined.

Tab. 2. Scenarios for equivalent conicity calculations

Rail head profile	Rail inclinatio n	Track gauge	Note
60E1	1:20 and 1:40	1435 and 1437 mm	4 cases
54E1	1:20 and 1:40	1435 and 1437 mm	4 cases
60E2	1 in 40	1435 and 1437 mm	2 cases

Tab. 3. Vehicles, limits for in service instability

Vehicle v_{max}	Equivalent conicity limit values	Test conditions from table 2
≤ 60	N/A	N/A
> 60 and < 190	0.30	All
≥ 190 and ≤ 230	0.25	1 to 5, 2, 3, 4, 5 and 6
> 230 and ≤ 280	0.20	1, 2, 3, 4, 5 and 6
> 280 and ≤ 300	0.10	1, 3, 5 and 6
> 300	0.10	1 and 3

The equivalent conicity value is determined at the following amplitude:

$\hat{y}$ = 3 mm, if (TG – SR) ≥ 7 mm

$\hat{y} = \dfrac{(TG - SR) - 1}{2}$, if 5 mm ≤ (TG - SR) < 7 mm

$\hat{y}$ = 2 mm, if (TG – SR) < 5 mm

At the other hand, in case instability motion appears, according to [1], the infrastructure manager shall measure rail profiles for equivalent conicity assessment at the site in question at a step of approximate 10 m along track. The moving average over 100 m shall be calculated and their maximum compared to limit value in table 4. The same wheel profiles shall be used as in case for new infrastructure.

Tab. 4. Infrastructure, limits for in-service instability

Speed range [km/h]	Maximum value of mean equivalent conicity over 100 m
v ≤ 60	assessment not required
60 < v ≤ 120	0.40
120 < v ≤ 160	0.35
160 < v ≤ 230	0.30
v > 230	0.25

4. EXAMPLE OF VEHICLE ASSESSMENT

In this example the wheels of the 4-axle track recording vehicle were measured and processed for equivalent conicity assessment. The vehicle has travelled about 2000 km after wheel machining.

Fig. 7 shows calculated equivalent conicities for amplitudes of the wheelset 3in the range from 1 to 7.5 mm, in combination with different prescribed rail profiles. The relevant amplitude is $\hat{y}$ = 3 mm. The highest value of $\tan\gamma_e(\hat{y}=3)$ = 0.239. For vehicle maximum speed of v=160 km/h this value is below the limit 0.30 given in Table 3.

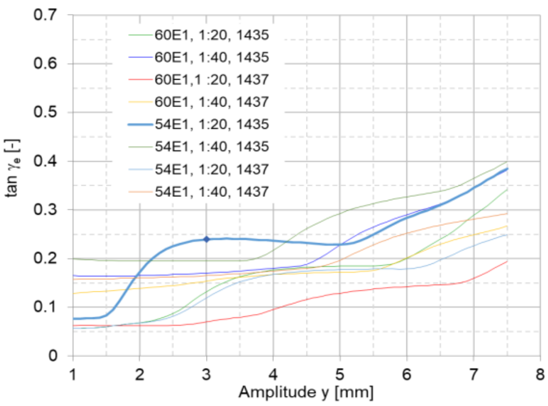

Fig. 7. Equivalent conicity, 3rd wheelset

For all sections, calculation is made in combination with prescribed wheel profiles. The highest values are obtained in combination with wheel profile S1002, and SR=1426 mm, as shown in Fig. 8.

Each line corresponds to one track cross-section. Relevant is the maximum 100 m moving average for amplitude $\hat{y}$ = 3 mm, which in this case equals to 0.158. This value is within both limits, for the new railway infrastructure (table 1) as well as for in-service instability (Table 4).

5. EXAMPLE OF TRACK ASSESSMENT

As an example, 300 m section of the right track on the new line between Belgrade and Novi Sad from km 56+700 to 57+000 is used. The rail profiles were recorded using devices of the track recording vehicle “SEVER 2000” of Infrastructure of Serbian Railways, with measurement step 25 m.

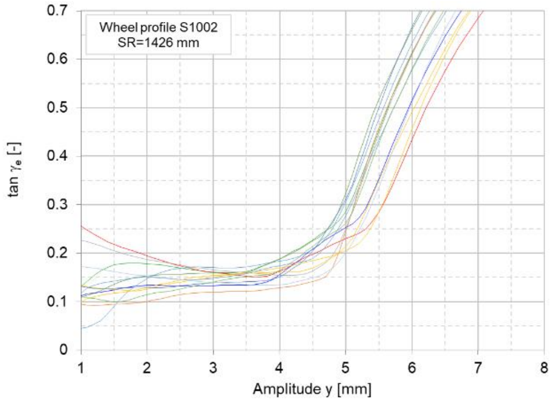

Fig 8. Equivalent conicity for track section example

6. CONCLUSION

With the introduction of the new Belgrade – Novi Sad line of Serbian Railways for 200 km/h, in-service control of equivalent conicity became extremely important. Presented requirements, calculation procedures and results examples can be considered as a guide for implementing actions.

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MODIFICATION OF THE POWERTRAIN UNIT ON A RAIL VEHICLE AND ANALYSIS OF ITS RUNNING PROPERTIES

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Abstract *– Nowadays, there is also a trend in rail transport to change to more environmentally friendly power cells. One such solution is the introduction of hydrogen fuel cells into the construction of rail vehicles. This paper studies the changes in the running properties of a modified rail vehicle and its components after replacing the standard diesel-electric powertrain unit with a new one using hydrogen fuel cells. This modification results in significant changes in the vehicle structure, especially in the mass and position of the centre of gravity of its various components. The running characteristics are analysed by simulation calculations using the commercial simulation software Simpack. A multibody simulation model consisting of rigid bodies connected by flexible force elements is used. This analysis is performed for both the original rail vehicle and the modified rail vehicle with hydrogen fuel cells. As a result, the modified rail vehicle with a hydrogen powertrain was found to have a similar force distribution in wheel/rail contact, but the axle load of this vehicle did not meet the criteria.*

Keywords – rail vehicle, powertrain unit, running properties, MBS modelling, simulation.

1. INTRODUCTION

Current environmental requirements to reduce vehicle emissions are pushing vehicle manufacturers to find new innovative technical solutions that will significantly reduce the production of harmful emissions during operation. These trends also apply to rail transport. However, there are places where electrification of the rail track is not possible or ineffective, so in these areas, independent powered rail vehicles are used [1]. These are rail vehicles that are either made up of a locomotive with an internal combustion engine pulling wagons or are complete multiple units. The second type of rail vehicle is now much more widely used as it offers several advantages. These multiple unit are also powered by an internal combustion engine, which produces unwanted emissions during operation, including CO2 [2].

Nowadays, there are several methods to reduce the production of unwanted gaseous emissions. Some involve the use of batteries, but they do not provide sufficient range for such rail vehicles. A more modern and up-to-date method and way of reducing the production of emissions is the use of hydrogen fuel cells as a source of energy to power rail vehicles [3-5].

The type of multiple unit powertrain based on the installation of hydrogen fuel cells is also the subject of the presented research. It is a diesel–electric multiple unit (DEMU) class 861.

However, such a modification of the rail vehicle requires a relatively significant intervention in its construction. This involves the replacement or removal of unnecessary components of the original diesel-electric power unit and the installation of new components necessary for the correct and reliable operation of the unit powered by hydrogen fuel cells [6]. The components comprising the power unit, both original and newly integrated, have a relatively high mass and are located at places where they are expected to have a significant effect on the operational dynamics of the rail vehicle [7]. The analyses make it

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possible to predict the dynamic characteristics of the multiple unit and their impact on the wheel-rail contact interaction.

2. MBS SIMULATION MODEL OF THE RAIL VEHICLE (MULTIPLE UNIT)

The analyses of the dynamic characteristics of the modified rail vehicle and its components due to the change of the powertrain and the influence of the wheel/rail contact interaction were carried out with the Simpack commercial software environment, specifically in its dedicated calculation module designed for rail vehicles, called Simpack/Rail. It is modern computational software that is widely used in analysing and assessing the properties of various types of mechanical systems [8]. As far as the Simpack/Rail module is concerned, it contains specialised modelling elements that make it possible to create a model of the rail vehicle as a whole. These are mainly the components of the rail vehicle, bogie components, and also a very important modelling element, namely the model of the wheel/rail contact [9, 10]. A more detailed description of the model of the class 861 multiple unit is given in the following chapter.

2.1. MBS model of diesel–electric multiple unit class 861 in Simpack software

The MBS model of the diesel–electric multiple unit takes into account all the components that significantly affect the dynamic characteristics of the vehicle during movement. It is a three-part rail vehicle with four bogies. Thus, the MBS model consists of the following main bodies: single body (three bodies - three rigid bodies), bogie frames - four rigid bodies, axle boxes - 16 rigid bodies, and wheelsets - 8 rigid bodies. In addition to these bodies, the model includes other necessary components that are essential for the completeness of the model.

The base model of the multiple unit is a model in which the mass and inertia parameters of the rail vehicle bodies are defined. These parameters are then modified based on the actual values given by the vehicle manufacturer. This involves defining masses and moments of inertia for bodies, bogie frames, wheelsets, etc. The centre of gravity positions for the propulsion components is defined, both for the original propulsion system consisting of a diesel-electric propulsion system and for the new propulsion system including the implementation of hydrogen fuel cells and the necessary additional components.

As a second step, the base model of the unit was modified to match the unit with the original powertrain, which included a diesel engine and other necessary components. These were integrated into the so-called RailPack unit (Fig. 1).

The third model of the multiple unit was based on the original model, with components defined

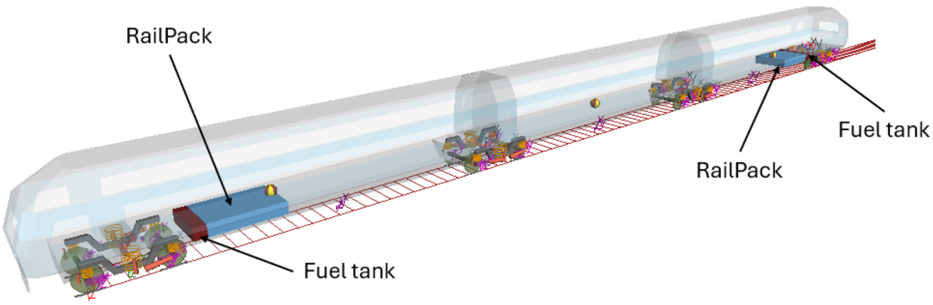

Fig. 1. MBS model of the diesel–electric multiple unit with the original power unit created in Simpack/Rail software

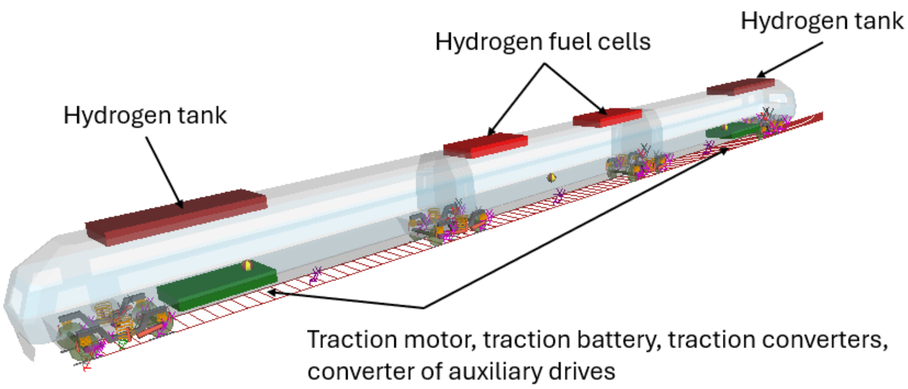

Fig. 2. MBS model of the hydrogen fuel cell multiple created in Simpack/Rail software

according to the layout of the components of the hydrogen-powered multiple unit. Fig. 2 shows the MBS model of the train unit created in Simpack/Rail, which corresponds to the layout of the hydrogen-powered components.

After creating MBS models of the multiple unit with the original diesel powertrain and the new hydrogen fuel cell powertrain, other necessary input parameters were defined to perform the simulation calculations.

This includes the creation of a suitable track model, a defined movement speed at which the multiple units will move during the analyses, and the determination of the monitored output parameters.

In the presented research the compared multiple units moved on the rail line, namely on the following line section Prievidza - Chrenovec. The defined movement speed of the rail vehicles is also related to the selected line sections. On the line, Prievidza - Chrenovec it was a movement speed of 50 km/h.

3. RESULTS OF SIMULATION CALCULATIONS

This section of the article presents the results of the simulation analyses of the rail vehicle moving under the conditions described in the previous chapters, i.e. on the specified track, at the specified movement speeds and the specified weight distributions for diesel and hydrogen powertrain (Fig. 1 and Fig. 2).

The force ratios in the wheel/rail contact are selected as output values as a representative output for the evaluation of the vehicle's movement characteristics. This evaluation pertains to the derailment quotient *Y/Q* and the vertical wheel forces *Q*. The results are presented for the front wheelset, specifically for both wheels individually, i.e., for the left wheel and the right wheel of the front wheelset.

Results are compared for the original diesel powertrain - red curves - and for the new hydrogen powertrain - green curves.

As a first output from the simulation calculations, we can see in Fig. 3 the derailment quotient *Y/Q* oscillogram. From the results, it is evident that both types of rail vehicle powertrains yield essentially identical derailment quotient values on the given track. Higher values are observed on the left wheel of the first wheelset, particularly noticeable in the first curve. The maximum permissible values for both diesel and hydrogen powertrains were not surpassed in any of the observed sections [11, 12].

Most important in terms of assessing the suitability of the hydrogen fuel cell powertrain of the multiple unit is the evaluation of the vertical wheel force

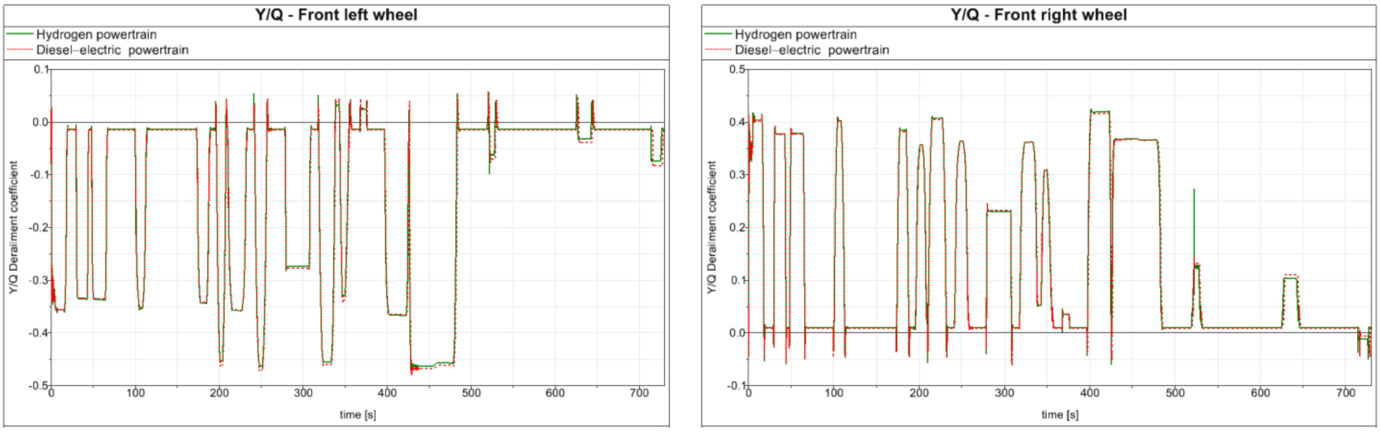

Fig. 3. Oscillogram of derailment quotient Y/Q, track Prievidza - Chrenovec, speed 50 km/h

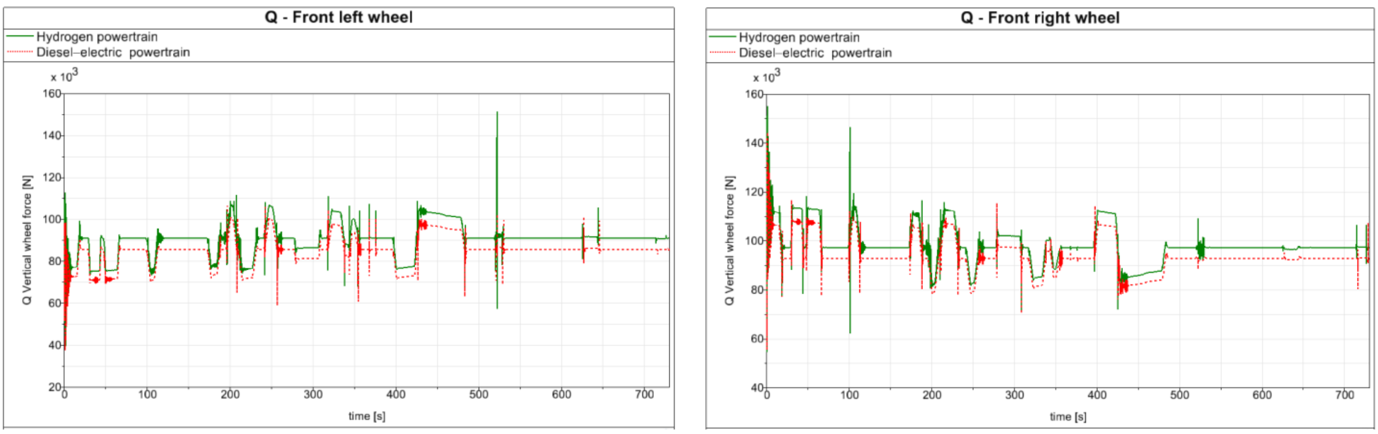

Fig. 4. Oscillogram of vertical wheel force Q, track Prievidza - Chrenovec, speed 100 km/h

waveforms *Q*. As can be seen in the graphs for the left and right wheels, the hydrogen-powered vehicle has a higher axle load than the original diesel-powered vehicle (Fig. 4). When a rail vehicle moves in curves on the rail track section Prievidza – Chrenovec the vertical wheel forces *Q* increase in the curves. In the straight sections of the track (horizontal parts of the graphs) it is possible to observe an increased axle load in the wheel/rail contact to the disadvantageously of hydrogen powertrain.

The most crucial finding is that the maximum permissible axle load is surpassed with a hydrogen powertrain.

The vehicle has a permissible maximum axle load of 18.5 t (181.49 kN), which is 18500 kg (181490 N) per axle. In the case of uniform weight distribution, the maximum load per wheel of this wheelset is 9.25 t (90.743 kN), which corresponds to 9250 kg (90743 N). However, it is clear from the calculated simulation plots that an axle load of 9.80 t (96.138 kN) or 19.6 t (192276 N) was achieved for the hydrogen propulsion system. Such an axle load on one wheelset is not permissible.

As a primary assessment of the simulation results, it can be concluded that the components of the hydrogen powertrain in the vehicle possess excessive mass, and their proposed distribution adversely affects the axle load of the modified vehicle. Therefore, it is advisable to reassess the installation of hydrogen powertrain components in the existing 861 class. It is imperative to utilize such components and adjust their distribution within the individual links of the vehicle to ensure that, in terms of vehicle loading and wheel/rail contact interaction, they adhere to the operational requirements, meeting the maximum axle load condition of 18.5 tons (181490 N).

4. CONCLUSION

The presented article focuses on the analysis of the movement characteristics of the modified vehicle and its components resulting from the change of the powertrain and its impact on the wheel/rail contact interaction. Multibody system (MBS) virtual models of the rail vehicle were created, with one version of the model equipped with a diesel powertrain and the other with a hydrogen powertrain. The simulation calculations revealed that the hydrogen powertrain has a detrimental effect on the axle load of the vehicle, resulting in a high axle load. Therefore, it is recommended to reconsider the installation of the hydrogen powertrain and its components in the rail vehicle with its current design.

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RESEARCH OF MECHANICAL PROPERTIES OF A REMOVABLE MODULE CONCEPT FOR TRANSPORT OF TRACKED VEHICLES BY RAILWAYS

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Abstract *–In order to increase the efficiency of railway transportation of strategic cargoes by railway transport, the design of a removable module is proposed, which allows adapting the body of an open-wagon to the transportation of Hessian equipment. The research is focused on the investigation of mechanical properties of a removable module concept. This module is proposed to be mounted on an open wagon and for transport of tracked vehicles and machines by it. The study of mechanical properties includes the strength analysis under its vertical load. The analyses are performed by means of the finite element method. At the same time, the Misses criterion was applied. It was established that the maximum equivalent stresses in the structure of the removable module concept are within the permissible limits. The conducted research will contribute to the improvement of the efficiency of railway transport operation, and it will be useful developments of the design of modern concepts of wagons' removable modules with a multifunctional purpose.*

Keywords – transport mechanics, open wagon, dynamic load, railway transport.

1. INTRODUCTION

Railway transport is a leading branch of the transport system, which ensures the development of the economy of many countries. At the same time, freight transportation is an important part of railway transport [1, 2].

Currently, the fleet of freight wagons consists of large number of wagons with different design features and production technology. Transportation of wheeled and tracked machinery is mostly carried out on platform wagons (Fig. 1).

Due to lack of platform wagons, there is a need for situational adaptation of the existing fleet of wagons for such transportation. An open wagon is one of such

a) b)

Fig.1. Transportation of wheeled and tracked machines on wagons: a) tractors; b) a digger

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type of wagon. However, at the same time, it is necessary to adapt its design to the transportation of tracked vehicles.

2. AN ANALYSIS OF THE RECENT RESEARCH AND PUBLICATIONS

An analysis of publications that are devoted to the issue of an adaptation of freight wagons to transport various types of cargo are covered in many publications.

The work [3] proposes a design of a removable module of the Flat rack wagon. A feature of such a removable module is a presence of flexible connections in the fittings. It helps to reduce the longitudinal load of the removable module when it is transported by vehicles. The scientific justification of the proposed design of the removable module is presented. The authors of the work did not investigate the possibility of using this removable module for attaching tracked equipment by an open wagon.

A special accessory is proposed in the patent [4] for the possibility of transporting heavy loads in on an open wagon. This accessory is a frame installed in the open wagon body. The frame also includes a partition and a load support. The operation of this device is described, as well as the advantages of its use in comparison with known analogues. The authors did not specify the possibility of fastening tracked vehicles or machines on a wagon.

Disadvantages of the existing schemes for fastening heavy loads on railway vehicles are discussed in [5]. A special device for fixing such loads is proposed to eliminate it. The advantages of its use, as well as the principle of action, are indicated. However, this device can mostly be used to fasten containers. Regarding the attachment of tracked machinery, its use is not practical.

For the possibility of transportation of heavy loads, the authors of the work [6] developed a special design of a flat wagon. To secure cargo, a wagon is equipped with vertical racks. The technology of loading and unloading operations on this wagon is described.

A similar design of the wagon was developed by the GreenBrier Europe company [7]. Such a wagon is intended for transportation of wheeled equipment, as well as containers. To ensure immobility of wheeled machinery, special stops are provided on the wagon. In the case of transporting containers, folding nozzles are used as fasteners. Undoubtedly, these wagon designs have significant advantages in operation compared to known ones. Along with this, the developers did not specify the possibility of transporting tracked vehicles on them.

The analysis of scientific works proves that the issue of transporting containers by open wagons is relevant, however, it requires further research.

In this regard, the purpose of the study is to highlight the special design and load capacity of the removable module for the transportation of tracked vehicles by railway.

3. A PRESENTATION OF THE MAIN MATERIAL OF THE RESEARCH

To adapt the body of an open wagon for transportation of tracked vehicles, a removable module design is proposed (Fig. 2).

This module is installed in the body of an open wagon, and it acts as an intermediate adapter between it and the unit of tracked machinery being transported. Fastening of the removable module on an open wagon body is carried out with the help of corner fittings. It is necessary to install fitting stops in an open wagon body (Fig. 3). The transported tracked machines are secured to the removable module using the fastening brackets. (shown in Fig. 1).

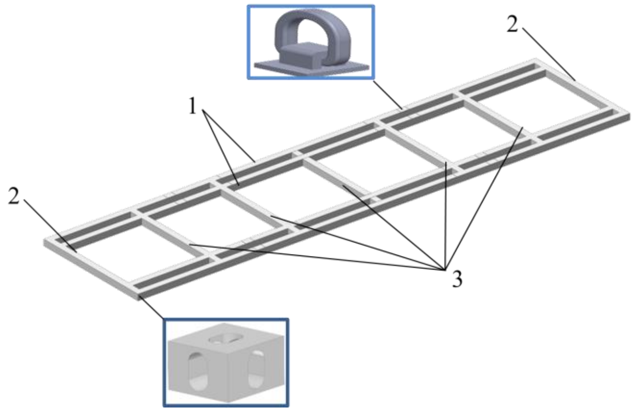

Fig.1. A removable module for placing tracked machines on an open wagon

In this case, it is possible to use slings or elastics. The supporting structure of the removable module (Fig. 2) includes four longitudinal beams (1), two cantilever beams (2) and five intermediate transverse beams (3).

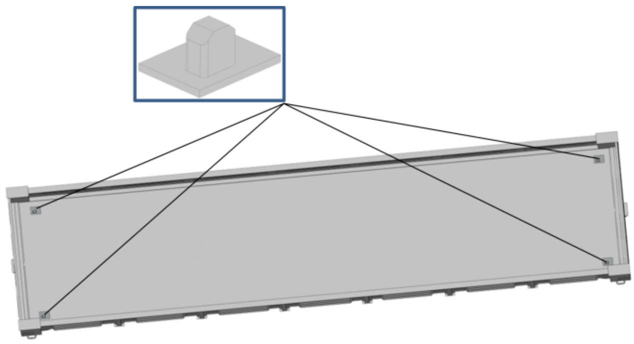

Fig.3. Positions of fitting stops on an open wagon body

At the same time, the profile of the detachable module is a square pipe (Fig. 4).

To determine the strength of the removable module when vertical loads are perceived, its calculation was carried out. The calculation scheme of the removable module is shown in Fig. 5.

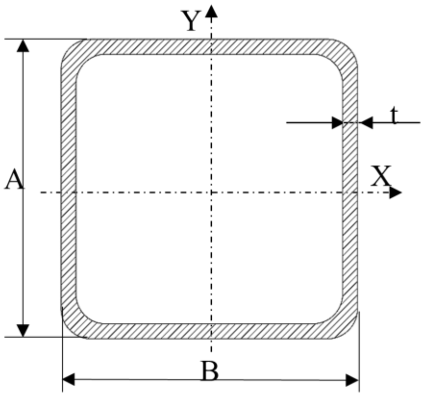

Fig.4. A cross-section of a square pipe: A - the height of the pipe; B - width; t - the pipe wall thickness

It is considered that the module perceives the vertical load P_v, which includes the vertical static and dynamic force components, as well as the loads acting on it from the fastening means. Since they are placed at an angle to the horizontal plane of the removable module, this load was divided into two components, i. e. vertical P_c^v and horizontal P_c^h. These components were determined considering the angle of inclination of the sling, which is 45°.

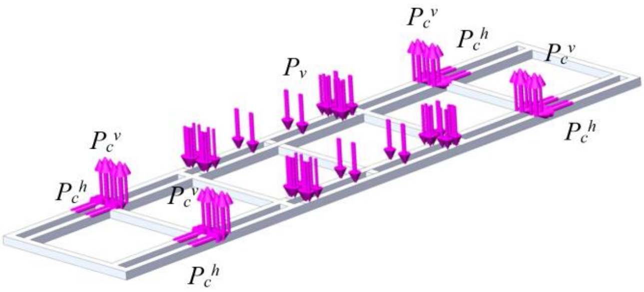

Fig.5. A calculation scheme of the removable module

The vertical dynamic load perceived by the lifting module P_{ct}^v was determined by the formula [8]:

$$P_c^v = P_{ct}^v \cdot k_{dv} \tag{1}$$

where k_{dv} is the coefficient of vertical dynamics.

The coefficient of vertical dynamics k_{dv} is considered as a random function with a probable distribution of the form:

$$P\left(k_{dv}\right) = 1 - \exp\left(-\frac{\pi}{4} \cdot \frac{k_{dv}^2}{\overline{k_{dv}^2}} \cdot \beta^2\right) \tag{2}$$

where $\overline{k_{dv}}$ is the average probable value of the coefficient of vertical dynamics, β is a distribution parameter.

The coefficient k_{dv} is defined as the quantile of expression (3) for the calculated one-sided probability $P(k_{dv})$:

$$k_{dv} = \frac{\overline{k_{dv}}}{\beta} \cdot \sqrt{\frac{4}{\pi} \cdot \ln \frac{1}{1 - P\left(k_{dv}\right)}} \tag{3}$$

The calculation was carried out under the loading condition the removable module from the tracked unit with the weight of 22.6 tons. The finite element method (FEM) was used as the calculation method. It is implemented in SolidWorks software [9, 10]. The FE model is formed by tetrahedra (Fig. 6).

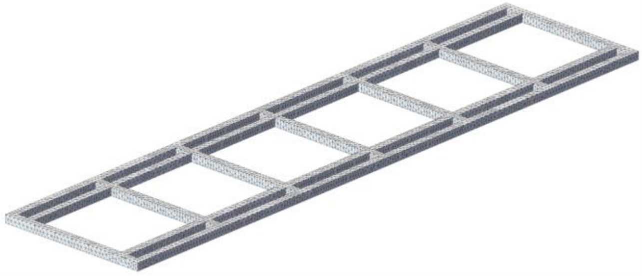

Fig.6. A finite element model of the removable module

The number of the elements is 52,965. At the same time, the model has 17,121 nodes. The boundary conditions included the fixing of the model using corner fittings.

The calculation results are shown in Fig. 7 to Fig. 9. It was established that the most loaded zones of the designed removable module are in its corner parts (Fig. 7). The maximum stresses are of 114.3 MPa (Fig. 8), which is lower than permissible value [8].

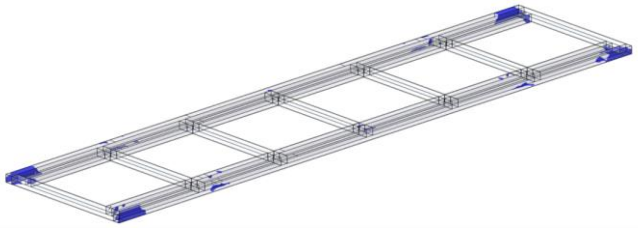

Fig.7. The most loaded areas of the removable module

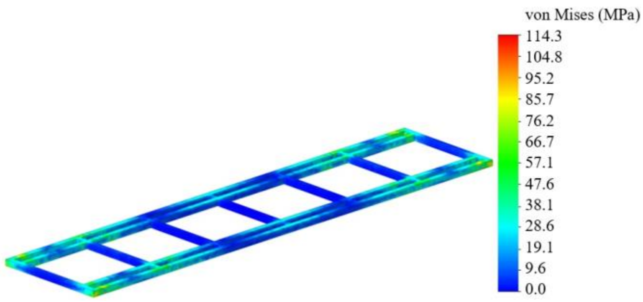

Fig.8. A stress distribution in the removable module

The maximum movements occurred in the second sector of the removable module from the side of the console, and they are equal to the value of 2.42 mm (Fig. 9).

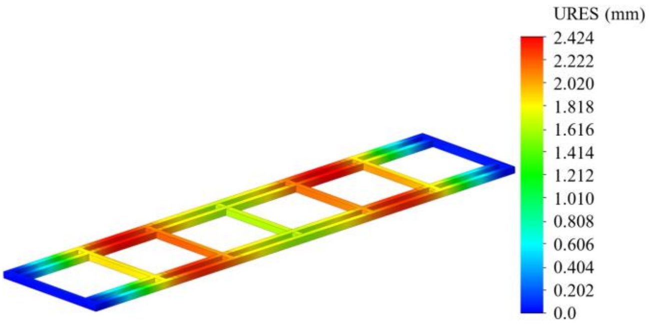

Fig.9. Displacements in nodes of the removable module

Therefore, the strength of the removable module under the considered load scheme of its design is ensured.

4. CONCLUSION

To adapt open wagons body for transportation of tracked vehicles, a removable module design is proposed. The peculiarity of such a module is that it acts as an intermediate adapter between the body of a wagon and on tracked machinery, providing the possibility of its placement, and fixing on an open wagon.

To study the strength of the removable module, a calculation was made. It was established, that the maximum stresses in its design are of 114.3 MPa and occur in the corner parts. The maximum movements occur in the second sector of the removable module from the side of the console, and they are amounted to the value of 2.42 mm. The obtained calculation results indicate that the strength of the removable module under the considered calculation scheme is ensured.

The conducted research will contribute to the improvement of the efficiency of railway transport operation and will be useful developments in the design of modern concepts of removable modules of multifunctional purpose.

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PASS-BY NOISE MEASUREMENTS USING ONE VERSUS TWO IDENTICAL TRAILER UNITS WITHIN AVAILABLE STANDARD METHODS

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Abstract *– This paper analyzes and compares the noise measurement results of rail vehicles obtained by testing with one or two identical trailer units. The test procedure for measurement of the pass-by noise emitted by railway vehicles is generally carried out using the standard method according to ISO 3095, for which it is necessary to perform the measurements with two identical trailer units. In special cases where a series consists of only one unit, i.e. there is no other identical vehicle, testing and signal processing are performed with just one unit. Typically, this is considered an exception. The requirements to provide two identical units can cause certain problems for manufacturers. If the need to modify the prototype arises, it implies changing the two vehicles, which results in increased costs. The paper shows a comparative review of the results and an opinion on the justification of the request to perform tests with two identical trailer units.*

Keywords – pass-by noise, standard test methods, single vs. two trailer units.

1. INTRODUCTION

Bearing in mind that noise tests are mandatory for all new wagons and that the testing of trailer vehicles must be carried out with two identical units, this paper analyzes the justification of having two units as required in the referent standard [1], especially given that for manufacturers, particularly smaller ones with less experience, this can be problematic. Any changes that need to be made to the prototype must be implemented on two wagons instead of one. In extreme cases, if the wagon does not meet all criteria and requirements during some type tests, two prototypes are rejected, not just one. The paper presents a comparative analysis of the measured values of the noise level for both mentioned cases according to the [1] methodology and offers an opinion on the obtained results.

In the papers [2,3], we presented results of the testing of several types of wagons according to the regular procedure from [1] with two wagons, while in this paper, we hypothetically explore what would happen if this requirement did not exist in the standard.

The idea for this comparison arose considering the possibility in the [1] to test just one unit, when there is no series in the classical sense, but the series consists of only one e.g. a special vehicle and manufacturer can provide only one car or wagon for type testing. In such a case, it is permissible to measure this single unit if it is acoustically symmetric. This shall, however, be considered as an exception since, according to [1], the procedure with single unit test leads to an increased measurement uncertainty compared with the regular method. The regular approach to testing is to inform the manufacturer that they are obliged to provide two vehicles under test from the same series.

2. SIGNAL PROCESSING

Applying the signal processing methodology, the characteristic separated parts of the signal were processed once for two identical vehicles (Fig.1.) during the period T_p of passing the middle of the first wagon to the middle of the second wagon by the microphone, and the second time the measurement record of single vehicle was analysed assuming that the vehicle under examination is at the end of the train and measurement time interval T (Fig.2.) begins when the

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centre of the unit passes the measurement position and ends when the noise level measured at the measurement position has decreased by at least 10 dB compared to the maximum noise level measured during pass-by of the unit. For the second approach $T_p = l/(2 \cdot v)$ corresponds to pass-by time of half of the unit where is:

l - length of the unit in m;

v - train speed in m/s.

For regular test with two identical units the A-weighted equivalent pass-by noise level $L_{pAeq,Tp}$ shall then be assessed by the following formula:

$$L_{pA_{eq},T_p} = 10 \cdot \log\left(\frac{1}{T_p}\int_0^{t_p}\frac{p_A^2(t)}{p_0^2}dt\right) \quad [dB] \qquad (1)$$

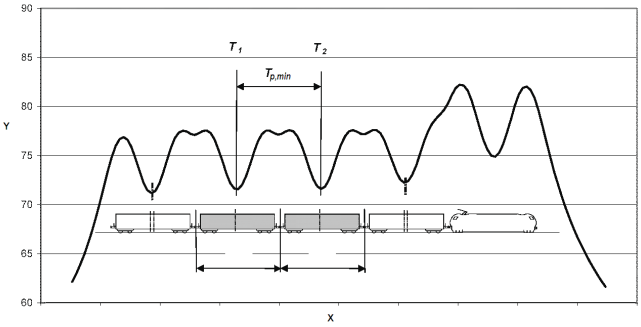

Fig.1. Example of selection of measurement time interval for test with two trailer units [1]

The A-weighted equivalent pass-by noise level $L_{pAeq,Tp}$ for testing of one unit according to [1] shall be assessed by:

$$L_{pA_{eq},T_p} = 10 \cdot \log\left(\frac{1}{T_p}\int_0^{T}\frac{p_A^2(t)}{p_0^2}dt\right) \quad [dB] \qquad (2)$$

where is:

$p_A(t)$ – the A-weighted instantaneous sound pressure at running time t in Pa;

T_p – the measurement time interval in s;

p_o - the reference sound pressure p_o = 20 μPa.

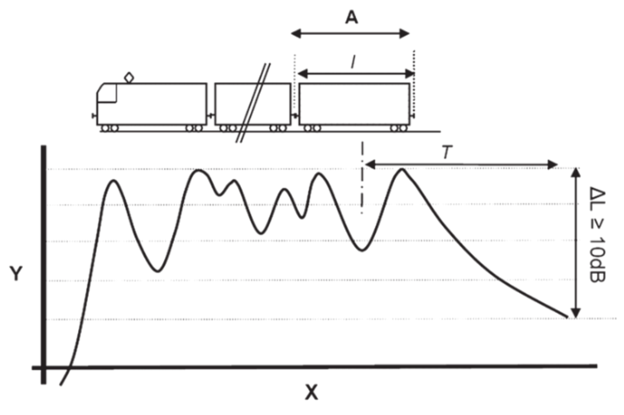

Fig.2. Measurement time interval where only one unit is being tested at the end of the train [1]

3. ENVIRONMENT CONDITIONS

Identical environmental conditions according to [1] as shown in Fig. 3 are provided for all tests. In both cases of testing, there must be an acoustically neutral vehicle in front, which emits a lower level of noise than the vehicle(s) being tested.

In the triangular area between the track and the microphone extending along the track to a distance twice the microphone distance to either side, shall be provided free sound propagation. The level of the ground surface over this area shall be within 0 m to −2 m, relative to the top of the rail. There shall be no reflective covering such as water, ice, tarmac or concrete. No absorptive material snow, tall vegetation or any obstacles shall be in the sound propagation path. No person shall be present in this area. The test performers shall be in a position that does not influence the measured sound pressure level significantly.

The following weather parameters shall be recorded during the noise measurement: wind speed and direction at the level of the highest microphone, temperature, humidity and barometric pressure. Any observed precipitation shall be noted. Heavy rain or wind speed higher than 5 m/s can affect the background noise. The maximum value of the $L_{pAeq,T}$ *during* T =20 s of background noise overall microphone positions shall be at least 10 dB below the $L_{pAeq,Tp}$ obtained when measuring the noise from the unit in the presence of background noise.

The measurement positions of the microphones for testing the trailer units with 120 km/h maximum speed shall be located at 7,5 m from the centreline of the track at a height of 1,2 m above the top of the rail [1].

The noise emission values are only comparable between sites where the track parameters are controlled and known to make them equivalent in terms of acoustic performance.

Fig.3.Sgmnss wagon type at the test site [6]

4. TEST RESULT

At least three measurements at 80 km/h ±5% and three at v_{max} =120 km/h ± 5% should be performed. Tab.1. to 6. present test results for three different types of wagons. Tab.7. presents the review of the results for all three series.

The first column presents raw $L_{pAeq,Tp(vt)}$ values. Each series gives values within the required maximum spread of 3 dB.

The third column represents the speed measured during the corresponding passing the train. It can be noted that all speeds are within ±5% tolerance of the nominal speed.

In the fourth column are given normalized values regarding actual speed and number of axles per lengths (APL) calculated according to the following equations:

$$L_{pA_{eq},T_p(APL_{ref})} = L_{pA_{eq},T_p(v_t)} - 10 \cdot \log(APL_{wag}/0{,}0225 m^{-1}) - 30 \cdot \log(v_t/80\ km/h) \quad [dB] \quad (3)$$

$$APL_{wag} = \frac{n}{L_{ob}} \quad (4)$$

n - number of axles and

L_{OB} - length over the buffers.

v_t - actual speed during the measurement.

After normalization, the arithmetic mean value of each series of measurements rounded to the nearest integer decibel is given for both cases.

Tab. 1. and Tab.2. present measurement results of 6-axle flat wagons Sggrss [5].

Tab.1. Measurement results with two Sggrss units

Test	$L_{pAeq,Tp(vt)}$ (dB)	v_t (km/h)	$L_{pAeq,Tp(APLref)}$ (dB)
80-1	83,3	79,59	83,3
80-2	83,6	81,20	83,4
80-3	84,7	80,73	84,6
120-1	88,5	119,70	83,2
120-2	88,4	117,82	83,3
120-3	88,4	119,54	83,1
Average rounded to the nearest integer			83

Tab.2. Measurement results with one Sggrss unit

Test	$L_{pAeq,Tp(vt)}$ (dB)	v_t (km/h)	$L_{pAeq,Tp(APLref)}$ (dB)
80-1	82,2	79,59	82,3
80-2	82,8	81,20	82,6
80-3	82,1	80,73	82,0
120-1	88,4	119,70	83,1
120-2	87,8	117,82	82,7
120-3	87,9	119,54	82,6
Average rounded to the nearest integer			83

If the test was conducted with one vehicle, the average rounded value is the same. On the other hand, the unrounded value is almost 1 dB lower in comparison with regular test with two units.

Tab.3. and Tab.4. present results of measurements with Zacns tank wagons [4].

If we compare the obtained values, we can see that the noise level in the case of one unit testing is higher by about 2 dB in comparison with regular test with two units.

Tab.3. Measurement results with two Zacns

Test	$L_{pAeq,Tp(vt)}$ (dB)	v_t (km/h)	$L_{pAeq,Tp(APLref)}$ (dB)
80-1	83,9	81,63	83,3
80-2	83,6	78,77	83,4
80-3	83,7	77,31	83,8
120-1	89,0	119,71	83,0
120-2	88,6	117,62	82,8
120-3	88,6	118,22	82,8
Average rounded to the nearest integer			83

Tab.4. Measurement results with one Zacns

Test	$L_{pAeq,Tp(vt)}$ (dB)	v_t (km/h)	$L_{pAeq,Tp(APLref)}$ (dB)
80-1	86,0	81,38	85,4
80-2	85,8	78,43	85,7
80-3	85,2	76,22	85,5
120-1	90,7	119,14	85,1
120-2	90,2	117,24	84,9
120-3	90,2	119,67	84,6
Average rounded to the nearest integer			85

The third type of wagon that was tested and compared is a flat wagon Sgmnss for transporting one container up to 40 feet long or some other equivalent combination of shorter containers [6].

Tab.5. Measurement results with two Sgmnss units

Test	$L_{pAeq,Tp(vt)}$ (dB)	v_t (km/h)	$L_{pAeq,Tp(APLref)}$ (dB)
80-1	81,5	78,97	80,4
80-2	81,3	80,30	80,1
80-3	81,3	78,92	80,3
120-1	86,3	117,68	80,1
120-2	86,9	117,59	80,7
120-3	86,3	117,65	80,1
Average rounded to the nearest integer			80

Tab.6. Measurement results with one Sgmnss unit

Test	$L_{pAeq,Tp(vt)}$ (dB)	v_t (km/h)	$L_{pAeq,Tp(APLref)}$ (dB)
80-1	84,4	78,97	83,4
80-2	84,4	80,30	83,2
80-3	84,4	78,92	83,4
120-1	92,8	117,68	86,5
120-2	90,3	117,59	84,1
120-3	92,4	117,65	86,2
Average rounded to the nearest integer			84

The difference in the obtained noise levels for this type of wagon is significant and amounts to 4 dB. This can lead to a completely incorrect conclusion about the noise characteristics of the wagon.

Tab.7. Pass-by noise tests results review

No.	Wagon type	Regular test with two units	Test with one unit
1	Sggrss	83 dB	83 dB
2	Zacns	83 dB	85 dB
3	Sgmnss	80 dB	84 dB

By reviewing the results from Tab.7. it is possible to see different deviations in both directions in the obtained results for different types of wagons, depending on the method of signal processing, i.e. the method of measurement with two or with one vehicle, because of different geometrical characteristics of wagons under test.

5. CONCLUSIONS

According to the performed tests, single-wagon testing is less reliable because the results are shown to be affected by the length of the unit under test. For longer wagons, the impact is less significant, so testing with one wagon yields similar or even lower noise levels. On the other hand, shorter wagons, are found to be more influenced and even noisier.

By analysing the recorded signals, it can be noticed that the time from the end of the wagon to the moment when the noise level becomes lower by 10 dB is almost the same for different types of wagons and consequently, a larger share in the total measurement time interval, in case of shorter wagons, could be the main reason for greater impact.

It should also be emphasized that the normalized reference $L_{pAeq,Tp(APLref)}$ values are significantly affected by the APL coefficient, which practically considers the density of the axles on each wagon. After measurement and normalization, similar instantaneous noise level for shorter wagons can result in lower equivalent noise level. This applies to both approaches of bass-by noise measurements.

In this way, the justification of the standard's requirement that measurement with one unit is less reliable than measurement with two identical ones is confirmed.

For a more reliable conclusion, it is necessary to carry out a test with larger number of wagons with different length and shape.

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CHALLENGES IN ENSURING THE QUALITY OF WELDED RAILWAY VEHICLES AND COMPONENTS

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Abstract *– During the production of welded railway vehicles and their components, standards such as EN 15085 are mandatory. Supplementary requirements, including those from the International Union of Railways (UIC), may also apply. "Quality assurance" in welding entails defined procedures to ensure product reliability. These conditions pose challenges, particularly in welding technology and personnel requirements. Crucial to this is the welding coordination staff, responsible for defining processes, reviewing product requirements, and overseeing implementation and control. Welding contractors must employ coordinators with relevant expertise aligned with EN ISO 14731 standards. Manufacturers must ensure qualified welders per EN ISO 9606-1 or operators per EN ISO 14732, depending on the product and welding process used. Using quality assurance in welding for brake triangles as an example, all requirements applicable to welding of railway components were examined for one manufacturer.*

Keywords – Railway, Welding, Quality Assurance, Reliable Product, Safety.

1. INTRODUCTION

Quality assurance in the production process encompasses all operational and organizational actions that ensure products possess meet the quality characteristics required by technical and technological documentation. A company's quality assurance program may include several stages, such as:

- Planning,
- Preparing technical documentation,
- The production process,
- Measurement and control in production,
- Product testing,
- Packaging and delivery,
- Market analysis,
- Product servicing.

In welding, "quality assurance" refers to the procedure a manufacturer must follow to ensure a reliable product. Requirements and guidelines are provided in the EN 15085 series of standards, based on the EN ISO 3834-2 [1] standard, which defines general quality requirements for fusion welding of metallic materials.

Welding is considered a special process, meaning the quality of welded joints cannot be fully tested on the welded elements or structures themselves. Certain methods requiring mechanical testing could compromise the integrity of the structure. Therefore, to confirm the quality of the desired weld, methods such as preliminary testing of the welding technology on reference samples, verifying the competence of personnel involved in the welding process, and additional activities defined by applicable standards, national regulations, or client requirements are used.

The requirements that manufacturers must meet are defined by the EN ISO 3834-2 standard. This standard mandates that the manufacturer undertake the following activities [1]:

- Review contracts, particularly technical requirements related to the product and the manufacturer's ability to adequately meet them,
- Review the need for and competence of subcontracted activities and services,
- Ensure the competence of personnel involved in production planning, manufacturing, evaluation, and control of the product,
- Ensure the adequacy of equipment used in production and in controlling critical product characteristics,
- Ensure the quality of materials incorporated into the product,
- Control the thermal cycle of welding and any post-weld heat treatments, if applicable,
- Evaluate the product and its characteristics through

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testing and examination,
- Manage non-conformities identified during production and implement corrective actions,
- Calibrate and validate equipment used for product evaluation,
- Ensure the identification and traceability of processes and materials incorporated into the final product,
- Maintain quality records.

All these activities and requirements prescribed by the EN ISO 3834-2 standard must be carefully considered, and the manufacturer must adequately respond to and apply them during production and evaluation.

2. QUALITY ASSURANCE ACCORDING TO EN 15085

In addition to meeting the requirements of EN ISO 3834-2, manufacturers must also adhere to additional product-specific requirements outlined in the EN 15085 series of standards. This series specifies certification requirements for manufacturers and quality standards for welding in new constructions or repairs.

2.1 Quality assurance and staff requirements according to EN 15085-1

EN 15085-1 [2] specifies general requirements for the entire series, covering welding of steel and aluminum alloys, including castings. These standards ensure that welded joints meet the desired quality through inspection and link design requirements with production outcomes.

The standard applies to all welded assemblies, subassemblies, and parts, regardless of the welding method (manual, semi-mechanized, fully mechanized, or automated), as defined in EN ISO 4063. The manufacturer has the freedom to choose the welding process, consumables, and joint preparation unless otherwise specified in the contract. The manufacturer shall demonstrate full control and the ability to achieve the required quality level, particularly through:
- Company certification;
- Qualification of welders and operators;
- Qualification of welding procedures and work samples.

2.2 Quality requirements and manufacturer certification according to EN 15085-2

The certification level depends on the Certification Level (CL) classes defined for each component or part of the railway vehicle being certified. Compliance must be verified by a recognized certification body. Three certification levels are defined [3]:
- CL1: For welded railway vehicles and components with high safety relevance.
- CL2: For welded components with medium safety relevance (high safety relevance not allowed).
- CL3: For components with low safety relevance (high or medium safety relevance not allowed).

In addition to certification levels, the standards outline requirements for staff involved in product execution and control. Competence is proven according to standard guidelines, with welding coordinators playing a crucial role. They are responsible for defining processes, ensuring compliance, and overseeing execution.

Welding coordinators must have relevant experience and technical knowledge, as defined in EN ISO 14731 [7]. The standards define three levels of competence for welding coordinators:
- Level A: Comprehensive technical qualifications and competencies.
- Level B: Specific technical qualifications and competencies.
- Level C: Basic technical qualifications and competencies.

Technical requirements for the manufacturer according to EN 15085-2 must include appropriate workshop conditions and suitable welding equipment in accordance with EN ISO 3834-2. At the manufacturer's request, the certification body verifies compliance with this standard, particularly:
- Welding personnel (coordinators, welders, operators)
- Welding technology specifications (based on WPQR)
- Welders' qualifications (EN ISO 9606-1)
- Mock-up tests (EN 15085-4)
- Compliance with technical requirements and workshop conditions
- Fulfillment of welding quality requirements in line with relevant EN ISO 3834 standards.

2.3 Design requirements according to EN 15085-3

Design requirements for railway vehicles and components are provided in EN 15085-3 [4]. Welded joints must meet specific structural requirements to ensure safe operation under static and dynamic loads. These are classified into three safety categories:
- Low: Failure does not directly affect functionality.
- Medium: Failure compromises functionality or endangers people.
- High: Failure poses a significant risk of injury and complete structural failure.

Welded joints in railways are categorized into six performance groups (CP A to CP CD), guiding inspection classes based on safety and load categories.

EN 15085-3 provides requirements for base and filler materials. All base materials must comply with CEN ISO/TR 15608, ensuring weldability according to relevant EN norms. The contractor must demonstrate welding capability (WPQR) following EN standards, with the most stringent qualifications applying to CL1 certification. The contractor must select additional materials that match the base materials' characteristics, ensuring proper storage conditions and handling practices.

When planning welding, sharp transitions, stepped transitions, and crossing multiple seams should be avoided. Stress concentrations in the structure should be minimized for seam placement. If these conditions are unavoidable, plan for higher inspection levels.

2.4 Production requirements according to EN 15085-4

All necessary documentation related to welding works must be prepared by the manufacturer and the responsible welding coordinator (Level A) for new constructions, upgrades, modifications, and maintenance of railway vehicles and their components. The welding work documentation, as per EN 15085-4, includes [5]:

- Manufacturing plans;
- Welding sequence;
- Testing plans;
- Welding procedure specifications (WPS).

For the production of brake triangles, which fall under class CL1, in addition to the mentioned qualified welding procedures (WPQR), Welding Procedure Specifications (WPS), and certified welders according to EN ISO 9606-1 [8], it is necessary for welders to undergo relevant mock-up tests on joints that are not directly qualified by the welder's certification. This ensures that each welder demonstrates their competence to perform the required welded joint to the expected quality.

Welding mock-up tests must be performed under the same conditions as the actual production process, with the presence of the Welding Coordinator and proper documentation. The preparation of samples and welding can be carried out according to the requirements of EN ISO 15613 [10]. If EN ISO 15613 guidelines are not followed, the Welding Coordinator must define the welding and inspection plan.

For welded joints requiring specific welding skills, not defined by standard qualification samples under EN ISO 9606-1 [8], mock-up tests are mandatory for welder qualification. Testing of mock-up samples will follow the guidelines of EN ISO 9606-1. The validity of mock-up tests and their production every six months can also be applied according to EN ISO 9606-1 guidelines.

Welding (Fig. 1.) must be performed by certified welders according to EN ISO 9606-1, and as previously mentioned, by welders who have successfully passed the work samples according to EN 15085-4 [5]. The welding of work samples must be conducted under the same conditions as the product, with the Welding Coordinator's presence required. The work samples are documented, and the test specimens are kept for at least 2 years after the expiring date.

Fig.1. Welding of the sleeve and pipe joint

For the production of brake triangles, the manufacturer defined a welding plan for the work samples and conducted tests on relevant samples to ensure welders demonstrated their ability to produce high-quality welded joints. Figure 2 shows a macroscopic cross-section of the welded and tested work samples for welders who successfully passed the test.

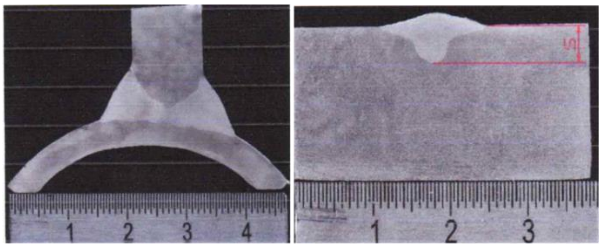

Fig.2. Macroscopic examination of the welder's working tests

2.5 Inspection, testing, and documentation according to EN 15085-5

Inspection, testing, and documentation of all activities are defined according to EN 15085-5 [6]. This standard covers:

- Inspection and monitoring of welded joints,
- Non-destructive and destructive testing to be performed,
- Required output documentation as proof of product compliance.

Inspection is divided into three phases: before, during, and after welding. After welding, qualified NDT personnel conduct visual testing (VT) and additional methods as required by the inspection class. Documentation must be identified in the quality system, with a traceable revision system. All documents are approved and archived by authorized personnel and considered quality reports per EN ISO 3834.

3. QUALITY OF WELDING

The most significant factors that can affect the quality of welding are:

- Welding Technique: Proper use of the welding process and technique.
- Material Properties: The type and condition of the materials being welded.
- Equipment Quality: Calibration and maintenance of welding equipment.
- Environmental Conditions: Temperature, humidity, and cleanliness of the welding environment.
- Welding Parameters: Settings such as current, voltage, and speed.
- Operator Skill: The experience and skill level of the welder.

Welding devices must be checked, with confirmation labels and certificates of conformity archived by the manufacturer in accordance with EN ISO 17662 [11] and EN ISO 3834-2 [1]. The inspection, calibration, verification, and validation of the welding devices ensure that the thermal regimes and welding parameters defined in the production process are accurately implemented. This is crucial because any deviation could disrupt thermal cycles, potentially degrading the mechanical properties of the materials, affecting the product's lifespan and safety.

After all the work is completed and the brake triangle is produced, it is necessary to conduct testing and verification to ensure compliance with the requirements of the EN 15085-2 series standards, particularly EN 15085-5 [6] and UIC 833 [12]. Testing includes both non-destructive and destructive methods. Non-destructive testing for brake triangles involves visual inspection of all welded joints according to EN ISO 17637 [13], magnetic particle testing as per EN ISO 17638 [14], and radiographic testing according to EN ISO 17636-1 [9]. Dimensional control is conducted by the manufacturer's quality control personnel using properly calibrated equipment, with an updated list of measuring equipment, including periodic calibration and verification dates.

After the welding process, Figure 3 shows the welded joints after cleaning and grinding, which were inspected visually according to the EN ISO 17637 [13] standard.

Fig.3. Welded brake triangle

Once all work is completed, it is necessary to verify the product's compliance with the documentation, focusing on the EN 15085-5 standard requirements and checking dimensions and measurements. Additionally, 100% of the welded joints are inspected according to EN ISO 17637 [13]. At the customer's request, the manufacturer is also required to inspect all welded joints using the magnetic particle method according to EN ISO 17638 [14].

4. CONCLUSION

For the production of railway vehicles and their components, adherence to regulations is essential when entering the international market, as these products may be used by various operators. The EN 15085 series of standards is applied in the production of welded railway vehicles and their components, and additional requirements from other standards may also be applied as needed. For the purposes of manufacturing the brake triangle and ensuring quality in welding while meeting UIC requirements, the manufacturer has demonstrated that all essential requirements have been considered and fulfilled, producing a reliable and safe product.

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CONSIDERATIONS ON THE EFFICIENT USE OF NIGHT TRAINS IN DAYTIME TRANSPORT

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Abstract *– As a result of the stricter climate protection targets in the European Union and the growing awareness of sustainable mobility, night trains are currently experiencing a renaissance. However, a major challenge for night trains is their economic operation. In conventional night trains, the achievable occupancy density is lower than in day trains. As a rule, seats are only allocated once for the entire run of the train. The personnel costs and, in some cases, the operating costs are often higher than for day trains. In addition, night trains are generally not in use during the day but are "unproductive" in carriage siding. As a result, many night trains do not cover their costs and have to be subsidised. In the TANA research project, concepts are being developed to increase the operating range of night trains by making their vehicle equipment suitable for use during the day. This will enable long-distance runs with better distribution functions in the pre- and post-carriage as well as operations exclusively during the day, which will avoid inefficient downtimes. The project clearly demonstrates whether and under what conditions night trains can be developed and put into service that are also suitable for use in daytime transport, taking into account the tight economic framework conditions. An overall system will be designed which, in addition to specific equipment features of the vehicles, will show suitable deployment scenarios, in some cases broken down into operational routes. The project will assess the economic efficiency and feasibility and propose concrete implementation measures.*

Keywords – night trains, day night use, HSR night trains.

1. INTRODUCTION

Night trains are a potential sustainable alternative to flights for medium- and long-haul routes. However, they are difficult to operate economically as they have a lower capacity compared to day trains and, due to their specific equipment, hardly have a sensible area of use in daytime transport. This results in unproductive, long idle times for couchette and sleeper carriages. Efforts have therefore been made to develop vehicle concepts that can be used equally in both daytime and night-time services. However, this involves compromises, as trains that are highly efficient in daytime traffic do not meet the comfort requirements of night travellers. Conversely, the use of standard night trains on daytime services is not economical as the achievable capacity is too low. Unless this is compensated for by the pricing.

Night trains account for approx. 20% of ÖBB-PV AG's total revenue [1] at and run for approx. 12 hours per day on selected routes. Day trains run for approx. 20 hours a day between 5 a.m. and 1 a.m. at night. It does not seem expedient to adapt day trains to the extent that they can also be used for night services, as economic disadvantages must be accepted for 80% of the range of services (measured in terms of revenue) and, conversely, the necessary compromises mean that the required quality cannot be achieved in night services. In addition, the requirements for vehicle ergonomics, accessibility and comfort factors also differ significantly. On the one hand, the usage behaviour of passengers differs greatly (rest, relaxation on night trains vs. work, communication on day trains), and on the other hand, travel times on night trains are significantly longer.

2. STATE OF THE ART IN EUROPE AND PROJECT APPROACH

The TANA project aims to develop a realistic overall concept for night trains that also enables a reasonable range of use in daytime transport. Elementary components of the design approach are the utilisation of multifunctional equipment elements, the development of complete vehicle systems and the derivation of suitable deployment scenarios.

The equipment of night trains is primarily geared towards overnight stays on the train. Different levels of comfort are used, which differ in terms of price, facilities and services:

- In the highest category, the sleeper carriages, compartments are offered with or without their own bathroom, which are generally used exclusively by one or more passengers travelling together.
- The middle category comprises so-called couchette coaches with simplified furnishings and usually compartments, often shared with other travellers, with four to six berths. New concepts, which are already being used on the ÖBB Nightjet, provide individual berths for better privacy.[3]
- The lowest comfort level comprises seating carriages (often compartment carriages, sometimes also saloon carriages).

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There are also so-called recliner carriages, but these also have a lower passenger capacity and have hardly become established, as only a certain seat inclination can be achieved, but not lying flat. In Norway, however, recliner carriages are being used again.[4]

In the countries of the former USSR, there are also “Platzkartny” carriages. These are travelling dormitories in which there are no doors between the bunks and the aisle and there are also couches on the other side of the aisle. The lower bunks can be folded down mechanically and then serve as seats or tables between the seats.[5] Vehicles that can already be used for night and day train services are seating carriages and, in some cases, couchette carriages, in which seats for up to six people per compartment are created by folding away the couches. However, seating comfort is limited by a continuous, non-adjustable bench seat. These carriages can already be used in daytime services at any time, although night trains currently usually form a continuous train formation that is not specially separated for daytime services. In principle, recliner coaches can also be used in daytime services and may be suitable for use as 1st class coaches. Couchette coaches with bunks do not appear to be suitable for daytime services, as the journey can only be made lying down. Sleeper carriages offer the most comfort, but allow a relatively low capacity, which means that they cannot cover costs or be used economically in daytime services with a normal fare scheme. Day trains are operated with classic seating coaches, which currently consist mainly of large-capacity coaches and have a higher capacity in UIC coaches in 2nd class with approx. 80 seats per coach than coaches in night train services (e.g. max. 66 seats in couchette coaches). Some daytime services, especially IC trains, also use compartment carriages, as on night trains. Currently less so in Central Europe, but certainly in other regions of the world, night trains also run on long-distance routes that last several days and where travellers sit in the same vehicles both at night and during the day. Very often these are tourist trains with correspondingly comfortable facilities and high fares[6], but sometimes they are also classic passenger trains, such as in Russia.[7] In general, night trains have the advantage of covering the regions well in the pre- and onward carriage. This means that they not only enable point-to-point connections between larger cities such as aviation, but also directly open up considerably more areas in the region.[8] In addition, night trains start in the early evening or run into the morning the following day, which is why a daytime part is also integrated into such journeys.

The TANA project is developing an overall concept for night trains that can also be used efficiently in daytime transport. Areas of application could be, for example

1. Night train connections with longer pre- and post-carriage times for more efficient connections to the regions and for more transfer-free direct transport.
2. Use as day trains in order to increase the efficiency of the night train rolling stock by reducing idle times.

3. CHALLENGES AND OPPORTUNITIES FOR USE IN DAYTIME TRANSPORT

The aim of the TANA project is not to restrict the quality of night trains, which is why real operational challenges must be taken into account. Rail operations are particularly restricted when arriving in larger cities during the morning peak, as the timetabled train paths are heavily occupied, especially by commuter trains, and there are hardly any train paths or platform edges available for night trains. On some sections of the route (e.g. Florence-Rome), night trains have to travel on HSR sections whose train paths are also well booked in the morning hours, which is why overtaking operations extend the de facto journey times.[9] It currently takes four to six hours to "dismantle and refit" overnight trains (cleaning, changing bed linen, catering, etc.). According to current quality requirements, a corresponding standing time must be planned for this period. At the same time, the current overnight train services are based on the infrastructure available at the departure and destination stations. Route extensions often mean that the infrastructure at the "new" departure and destination stations would first have to be created. The use of HSR night trains also sounds promising for extended areas of operation, as very large destinations can be travelled at night. On the other hand, there are currently the challenges that numerous HSR line sections in Europe are either intended for (relatively slow) goods train journeys at night or are closed for maintenance work. Another economic challenge is that some of the main production costs for a night train increase linearly with distance and, for labour law reasons, two shifts of staff are required from certain journey times. However, it is not possible to adjust fares according to distance without restriction, particularly in night transport. This is a competitive disadvantage compared to air transport, where costs increase sublinearly with distance.[9] The challenges presented in the overview, which are not exhaustive, are intended to illustrate that long-distance or HSR night transport services cannot currently be pursued without restrictions and at the same time economically. Conversely, however, they are not intended to destroy the appealing idea of expanding services, which is why the TANA project is also looking for future-proof solutions. In order to achieve approximately the seating capacity of single-decker day trains for night trains in daytime operation, the design of the required adaptive equipment elements was based on a double-decker train concept. In order to eliminate restrictions on the use of HSR sections and at the same time not to restrict the possibility of future HSR night train operations, an HSR double-decker concept was used, which corresponds to the Euroduplex.

4. PASSENGER REQUIREMENTS

An online survey was conducted to ascertain the requirements. The results show that more than 60 per cent can imagine using night train connections that exceed a journey time of 16 hours. There are some basic requirements for vehicles that should offer a comparable level of comfort both during the day and at night. The majority of respondents were in favour of modern and bright equipment concepts. On the other hand, those that were perceived as very cramped and oppressive were criticised. On the other hand, coach interiors that allow travellers a certain degree of flexibility during the journey were praised. This includes work areas and facilities, as well the option to sit or lie down during the journey. Issues relating to sitting and sleeping comfort are generally among the most important requirements. At night, a comfortable place to lie down or sleep is the most important requirement. During the day, it is comfortable seating, whereby comfortable seating is also important for almost 80 per cent of respondents on an overnight train. For longer night train journeys in particular, respondents would most like to be able to convert the bed into a seat. When it comes to seating, the majority of respondents want a familiar sitting position, with adjustable seats being viewed very favourably. The arrangement of seats at right angles to the direction of travel is viewed rather negatively. In addition to seating and reclining comfort, there is also the space available for travellers. The concepts also give rise to clear points of criticism if the seats or reclining areas are perceived as too narrow or legroom is restricted. There is also a strong need for individually adjustable lighting and temperature regulation. Another important issue is privacy and security on the train. The need for privacy and lockable compartments is greater for night trains than for travelling during the day. Sleeping compartments that cannot be locked and those that are not opaque are viewed critically by the majority. There is also a recognisable tendency for people to refuse to share a compartment with strangers at night. Future carriage concepts should therefore be designed more for smaller compartments and individual sleeping berths that can be locked and are opaque. Wi-Fi is one of the three most important requirements for day and night trains. Work facilities are required much more frequently for travelling during the day than for night trains. In addition to Wi-Fi, this primarily includes desks that are arranged and dimensioned in such a way that they allow passengers to work properly. The results also show that sufficient space for luggage on day and night trains is an important requirement. At the same time, luggage storage should be secure, especially at night, so that travellers do not have to worry about theft. Carrying bulky luggage and bicycles is only important for just under a third of respondents both during the day and at night. Nevertheless, future vehicles should have multi-purpose areas in which bicycles or skis can be transported. Passenger information on the train is one of the most important requirements for those surveyed for day and night trains. There is a lot of potential for improvement here, especially for future night trains. At present, electronic passenger information systems are not the norm on night trains. In future, these should be implemented on night trains in a similar way to the systems on day trains. Separate family and women's compartments are more important to respondents on night trains than when travelling during the day. The results show that women want these much more frequently. In the case of women's compartments, as many as three quarters of all women would like to have their own compartments on night trains. Just under 45 per cent would also rate separate business compartments positively. This could appeal to affluent business travellers in particular, as the results show that almost a third of respondents have already used an overnight train for a business trip. On night trains, there is also a greater demand for services such as drinks and food. Similarly, the respondents would like to see snack and drinks vending machines on the train. These would offer the advantage that travellers could provide themselves with food and drinks at any time during the journey and this service would tie up fewer staff resources. On the one hand, the ticket price shows that it plays an important role in the decision in favour of or against a means of transport. The ticket price was rated as more important than comfort or journey time. Nevertheless, there is a tendency to recognise that comfort plays a more important role in the choice of means of transport with increasing age of the respondents. On the other hand, a willingness to pay higher prices for more comfort can be recognised. On the other hand, there is less willingness to pay more for night train tickets than for travelling during the day, unless the service is seen as very comfortable and can also convince in terms of privacy, safety and facilities.

5. INTERIOR DESIGN

The first interior design concepts are presented below. At the centre of the design of the day and night train is a multifunctional interior concept that offers passengers an individual and comfortable travel experience, regardless of whether they want to relax, work or sleep. The aim was to create spaces in which travellers enjoy spending time and which can be adapted to individual travel needs. The aim is to create an alternation between a personal retreat with the greatest possible comfort and a more open design for relaxation or the opportunity to socialise freely. The understated and timeless aesthetic creates a unique travelling environment in which passengers can immerse themselves and unwind from the hustle and bustle of everyday life. The result: a forward-thinking, inviting design that appeals to the senses without overwhelming them.

Fig.1. Single berth on the upper deck, design day and night train (© moodley)

The concept is based on the experience of designing first-class aircraft cabins inspired by the comfort of a living room, but offering maximum comfort in a small space to provide sufficient capacity. Lockable individual berths with half-height partition walls offer privacy and a special space for concentrated work on board. The acoustic panels of the flexible room-in-room systems can also be installed at ceiling height and reduce ambient noise. There is sufficient space under the seats and in the footwell for stowing several items of luggage.

Fig. 2. Example of a zoning concept for the upper deck (© moodley)

Different zones with different functions are offered based on the various user requirements. Separate lockable family and women's compartments or business compartments allow more private use for up to four people during the day and offer space comfort and security for two at night.

Fig.3. Private compartments with pull-out bed function & modular seat design (© moodley)

Private compartments in the lower deck can be configured variably and offer small groups space for personal conversations and interaction. Lockable 4-seater compartments (Fig. 3 left), which are connected to the structure of conventional seating car compartments, through to comfortable 2-seater, 3-seater and 4-seater sleeping compartments with integrated wet room and storage space for large items of luggage have been designed. Other advantages include the option of connecting your own devices to the train's entertainment system and, depending on the operator's service concept, it may also be possible to order an on-demand menu via this system. The basis of the minimalist interior concept is a multifunctional modular seating system (Fig. 3 right) that combines comfortable sitting, reclining and sleeping (e.g. at night or in the early morning). The use of identical parts in combination with additional features enables travellers to create seating configurations for activities such as eating, relaxing, reading or working.

Fig.4. Private compartment & Space-saving sleeping concept (© moodley)

The seats have wider seat, back and head cushions that can be converted into a fully-fledged bed (Fig. 4 left). The space-saving memory foam upholstery ensures comfort in any sleeping position. All seats offer practical features (Fig. 4 right) such as work tables with special work lighting, reading lamps, power sockets, inductive charging stations for mobile devices, coat hooks, wall brackets for personal items and integrated seat speakers for a relaxed experience.

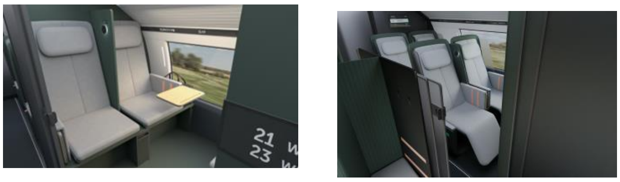

Fig.5. Mono-material seat & storage space for luggage in the seating area (© moodley)

Sufficient storage space is a recurring need for passengers. Openings under the seats (Fig. 5 left) offer the option of storing luggage or shoes directly at your seat and spacious, lockable luggage racks in the carriages offer this option for larger items of luggage. The interior concept takes sustainability and resource conservation into account. Special attention was paid to accessibility and barrier-free access. Wider entrances, easily accessible seats with armrests that can be adjusted downwards (Fig. 6 left) make it easier to sit down and stand up. Floor markings and tactile elements provide orientation for visually impaired passengers, while LED light signals (Fig. 6 right) also guide users through the space at night. The room is pleasantly illuminated by more extensive daylight, while the atmospheric ambient lighting can also be changed in colour to suit the time of day and promote relaxation and well-being.

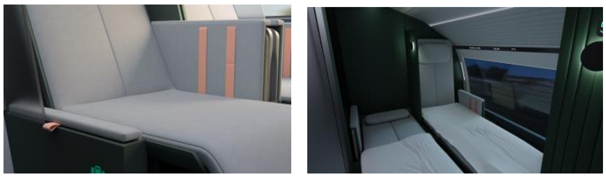

Fig.6. Night view of the private compartment on the upper deck & adjustable armrest (Image: © moodley)

6. CONCLUSION

The project deliberately chose to "rethink" night train components. Even if many elements give the impression of being familiar, the new concepts, particularly in the compromise area of day and night operation, represent completely new approaches to space-saving room structures that enable both the necessary seating capacity in daytime operation and the necessary and desired privacy in night-time operation, and which can be chosen above all by price-sensitive passengers. In the higher-priced segment, closed compartments with corresponding equipment elements that offer extensive privacy and fulfil comfort requirements in the best possible way will continue to be promoted. These concepts are analogous to new types of sleeper cabins, although here, too, greater flexibility has been emphasised. The TANA project will run until June 2024, and potential areas of use for the corresponding rolling stock will be developed in the further course of the project with a view to economic operation.

ACKNOWLEDGEMENT

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ANALYSIS OF STATION'S CAPACITY REGARDING THE APPLIED INTERLOCKING SYSTEM, ON THE EXAMPLE OF THE TENT KALENIC STATION

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Abstract – *Capacity of railway station is highly dependable on used interlocking system and traffic management pattern. Interlocking system's improvement requires significant financial resources, while traffic pattern could be changed by applying different management rules, depending on transport demand. This means that it is desirable to determine a certain trade-off between these parameters, up to the maximum capacity utilization index with the existing interlocking system. Several methods have been developed that consider given parameters for station capacity determination. In this paper we compare some of the methods for capacity determination, using the example of the Kalenic station, which was recently taken over by TENT from another industrial system.*

Keywords – railway, station capacity, capacity utilization index, traffic pattern.

1. INTRODUCTION

Thermal Power Plant "Nikola Tesla" (TPP NT) is a power plant complex in the Republic of Serbia operated by Elektroprivreda Srbije (EPS). TPP NT is the largest electricity producer in the Southeast Europe. Annually, TENT generates more than 50% of electricity in Serbia. TPP NT has the industrial railway – a railway managed by a business entity and used for the transport of goods and/or persons for its own business. Their industrial railway has highly intensive rail traffic with 50 pairs of trains per day, transporting mostly coal, but also materials and equipment for TPP Kolubara and TPP NT and other users. One train usually consists of 27 wagons, and an average cargo of 1,520 t. The daily volume of transport is 76,000 t of coal, and 2,300,000 t monthly. The industrial railway with this volume of work is one of the busiest railways in Europe. TPP NT invests permanently in its railway system so it works more efficiently, reliably, and safely.

An interlocking system plays a crucial role in ensuring safe and efficient railway operations by preventing accidents caused by conflicting movements on tracks. It ensures that only one train is allowed to enter a specific section of track at a time, thus preventing collisions and ensuring safe operations. The system uses electronic technology to monitor the position of switches and signals, as well as the presence of trains on the tracks. There are many benefits of using the modern interlocking system such as the capacity of railway stations, enhancing compliance with safety regulations and standards, and improving productivity and efficiency of the railway system.

By opening a railway market and with more actors in the railway market, the capacity of the railway infrastructure has become a bottleneck for the entire railway system [1]. As a result, the quality of transport services has diminished, primarily due to increasing train delays and the reliability of transport services. Efficient capacity utilization is a railway challenge around the world. The paper [2] emphasized that railway capacity is a very complex concept due to many relevant factors such as infrastructure, rolling stock, signaling and operation planning. In their paper, over 60 papers related to railway capacity have been examined and the contributions are summarized.

2. CAPACITY CALCULATION METHODS FOR THE SWITHCING AREAS

Infrastructure capacity represents the number of train movements that can be realized in the considered time. Capacity utilization index can be calculated either as a ratio of the number of operating routes and all possible routes within given time interval, or as a ratio

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of switching area occupation time and total observation time.

Today, there are several widely accepted methods for capacity utilization assessment of the switching area. All of these methods assume already defined traffic pattern, in terms that sequence of the running routes is known, or, at least, that the probability of the next route could be determined, for each successive route.

Within this paper, Potthoff method [3] and method proposed by UIC 406 Leaflet [4], will be discussed.

2.1. Potthoff method

The Potthoff method is based on global analysis of the traffic pattern within time period T. At the very beginning, method requires topological analysis of the switching area in order to mutually compare all assumed (possible) routes. The most convenient data structure for this task is compatibility matrix, in which rows and columns represent all considering routes. Each element in such a matrix represents compatibility or incompatibility of the two routes (at intersection of the given row and column). Two routes are mutually incompatible if they are mutually intersecting, diverging, converging, consecutive at same infrastructure element, frontally in a collision, or if the row and column represent the same route.

After competition of the compatibility matrix, the number of all movements should be determined, considering each predicted route, in order to determine the average number of compatible routes. To obtain the average number of compatible routes, the respective weight coefficient for each pair of routes should be calculated as:

$$n_i \cdot n_j \quad (1)$$

and the average number of compatible routes will be calculated as:

$$n_{med} = \frac{N^2}{\sum(n_i \cdot n_j)} \quad (2)$$

where:

- N represents total number of movements,
- n_i number of movements considering route i,
- n_j number of movements considering route j.

For all mutually compatible routes, the respective weight will have value equal to zero.

In the following step, the matrix of occupation times has to be formed. Within that matrix, the elements with $i = j$ will have the value of infrastructure occupation time with route i, while for elements with different routes ($i \neq j$), the value represents the period during which the route j may not be run, because the is an incompatible movement on route i.

After the determination of each element t_{ij} of occupation matrix, the average occupation time is calculated as:

$$t_{med} = \frac{\sum(n_i \cdot n_j \cdot t_{ij})}{\sum(n_i \cdot n_j)} \quad (3)$$

At the end, the total occupation time, *B*, and capacity utilization index, U, should be calculated, for the station, or switching area, as a whole:

$$B = \frac{N}{n_{med}} \cdot t_{med} \quad (4)$$

$$U = \frac{B}{T} = \frac{N}{n_{med}} \cdot \frac{t_{med}}{T} \quad (5)$$

where *T* represents total observation time.

Further, method allows us to rate traffic pattern quality, through calculation of the total delay generated within the switching area, as the sum of all delays related to each pair of incompatible routes, since each movement forbids movements of all incompatible routes. For calculation of those generated delays, probability of the next movement should be introduced, as well as some other assumptions, such as FIFO type of service, regardless of train ranks. Also, to conduct a complete quality assessment, apart from route pairs, one should consider probability of simultaneously route execution with each set of two compatible routes, three compatible routes, and so on.

2.2. UIC method

A procedure for capacity calculation recommended by UIC is based on compression method. In practice, it means that all route paths should be as close as possible to each other, i.e. at minimum headway time.

Hence, at first step, minimum headways for each route pairs have to be obtained. For the duration of minimum headway time, considered movement is excluded by another movement. As, by definition, headway time represents a time period between passing by a point of two consecutive trains, the minimum headway time is calculated as the moment when the consecutive movement could start after the start of the previous movement. If the two movements are compatible, and therefore they could be run simultaneously, minimum headway time would have value of zero.

All minimum follow-up times between each pair of the assumed routes should form a matrix, very similar to compatibility matrix from the previous method.

Further, a timetable or route sequence has to be available; the UIC method for capacity calculation of the switch area requires a movement sequence as a necessary input.

This method assumes that each route's occupation time starts as soon as possible, after the preceding movement, regarding calculated headway time. Since the minimum headway time has a value of zero for compatible movements, parallel movements are taken into consideration.

The goal of the method is to obtain the total of all occupation times, which should result as the sum of all excluding times of concatenated movements.

To obtain total occupation time, table should be prepared in a way that the number of columns should be equal to the number of all possible routes increased by 2, while number of rows should be equal to the number of the movements provided by the timetable in a given time period, increased up to 3 rows, to provide repetition of the first two or three movements in order to disable "open end" of the timetable – this is requirement from timetable cyclicity.

The first movement should be placed at 0.0 minute, i.e. it is assumed that it starts immediately with observation period. After that, the first row should be populated with minimum headway values, regarding all other assumed movements. Further, at the beginning of each row, as starting time for the next movement the next the corresponding value from the previous row should be taken and then. For each row, the end of occupation times should be obtained by summarizing values from previous row and corresponding values from minimum headway matrix. In the case of compatible movements, the minimum headway time is equal to zero and it is possible that calculated value is lesser than the one in previous row, in which case it should be replaced with higher value.

Previous procedure should be repeated for all assumed movements according to given timetable, and for the repetition of first movement, from the first row.

Finally, the total occupation time is defined by the starting time of the additional movement (repeated the first one) and occupation time rate is calculated as:

$$OTR = \frac{t_{n+1}}{T} \cdot 100 \quad (6)$$

where t_{n+1} represents starting time of the additional movement and T represents observation time.

At the end, going backward the number of concatenations can be obtained. This number represents the chain of the execution of mutually incompatible movements, since some of the compatible are executed simultaneously. Ratio of the number of concatenations and total number of movements assumed by the timetable, give us the concatenation rate, φ, which explains incompatibility of given traffic pattern.

Considering selected methods for the capacity determination of the switching area, it could be concluded that capacity, apart of the switching area topology, greatly depends of implemented interlocking system. Modern interlocking systems enable shorter minimum headway times, which are the most important capacity parameters.

Introduction of the new, modern interlocking system demands significant financial investment, and usually it is delayed as much as possible. With the increase of the capacity utilization, switching area may become bottle-neck for the entire line, or even part of the network. Although there is no exact guidance when to upgrade interlocking system, usually capacity utilization rate of over 65% is considered critical, since the service quality significantly decreases with its incrementation. For the capacity utilization rates beyond 70% service quality is often very bad, while no operational measures could not be taken in order to decrease capacity utilization rate. That's why the capacity utilization rate of 60% is considered as trade-off point at which interlocking system modification or upgrade should be considered.

3. CAPACITY DETREMINATION FOR THE TENT KALENIC STATION

Railway station Kalenic in the past years was incorporated into TENT railways system from another industrial governance. The station represents the connection between railway network managed by Infrastruktura Zeleznica Srbije and transport system within TENT. At the moment, all switches in the station have to be set manually on the spot, and after setting to the required position, switches must be locked and keys have to be taken to the train dispatcher, for visual confirmation of the correct position.

Schematic view of the station is shown in Figure 1.

For the case study, we considered an average operational day, with total of 45 movements, of which 15 were shunting movements.

Both methods gave capacity utilization rate between 20 and 25%, which is relatively small utilization and, under the observed condition, the modernization of interlocking system should not be considered. Exact results are shown in Table 1.

Tab. 1. Capacity utilization for different calculation methods

Calculation method	Utilization rate [%]
Potthoff	21.94
UIC	24.24

The difference in the obtained results arises from the fact that Potthoff method does not consider exact route sequence, but the relative probability of upcoming movement, determined through the route frequencies within given traffic pattern.

As an operational rule, for shunting movements, safety zone is not the necessary requirement. That leads to the shorter minimum headways between two or more consecutive shunting routes. If a mandatory safety zone were to be introduced, immediately after the intended end point of the shunting movement, the capacity utilization rates would increase, but not significantly, since the total number of planned shunting movement is one third of the total number of routes (Table 2).

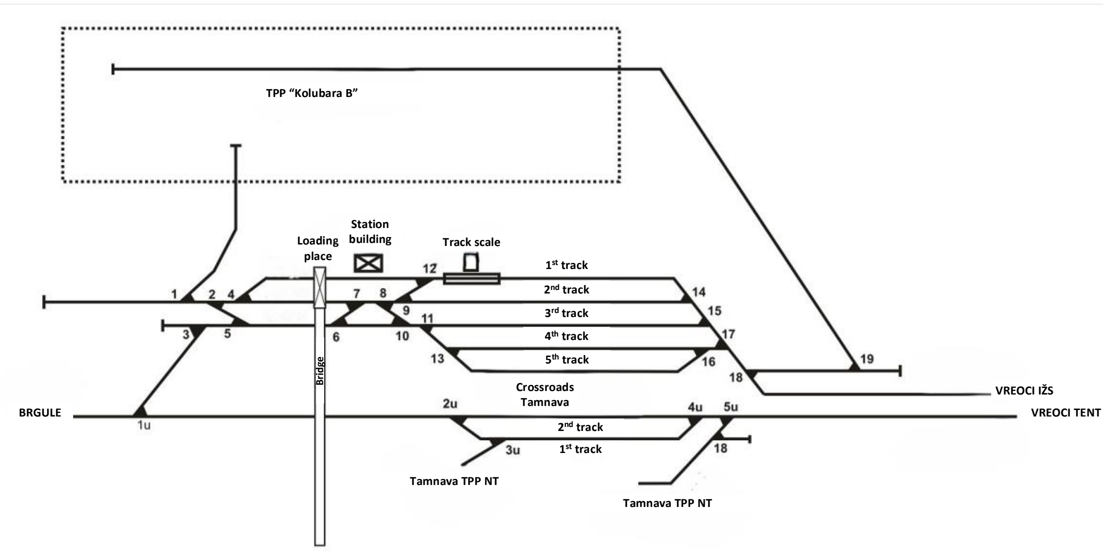

Fig. 1. The Layout of the Kalenic station

Tab. 2. Capacity utilization for different calculation methods and for required safety zone for all routes

Calculation method	Utilization rate [%]
Potthoff	24.38
UIC	28.17

For the next period, even with the increased traffic volume, operational measures should be sufficient to maintain the capacity utilization rate at the desired level.

4. CONCLUSION

In the previous period, the railway station Kalenic has been taken over for operations by TENT. The station is not equipped with modern interlocking system and all switches are setting up manually, on the spot.

However, according to the average transport volume examined for the one operational day, station capacity is sufficient for the satisfactory quality of transport service. Capacity utilization index is around 25%, which was obtained using two different calculation methods.

In the following period, especially in the case of an increase in the transport volume, attention should be directed to the side of the Kalenic station towards Vreoci, since the topology of the station is such that most routes from that side are mutually incompatible.

If one considers the potential modernization of the applied interlocking system, due to the relatively low level of capacity utilization, the eventual multi-stage application of modern systems should be considered, so that the level of investments could follow the potential gradual increase in transport volume.

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DISCUSSION OF DIFFERENT TOPOLOGIES FOR STATION RESNIK

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***Abstract** – The planned redesign of station Resnik in the south of Belgrade is a good example of questions popping up for the future track topology. Of course, it strongly depends on the traffic forecast and the planned timetable. The challenge is to find a solution which offers a high utilisation of station tracks but also some reserves for future demand. Thereby, operational conflicts should be minimised by the layout itself. Looking at the costs of such a measure, one half is the investment and the other half is the maintenance during the life cycle. Therefore, too many tracks and switches will require more maintenance than less infrastructure assets. In this paper several solutions will be presented and discussed upon their advantages and disadvantages.*

***Keywords** – railway planning, railway stationlayout, infrastructure design, simulation.*

1. INTRODUCTION

The topology of historical railway stations typically has a high level of complexity due to several steps of past extensions. When having the chance to renew all infrastructure assets in a railway station, the main question is what do we need now and in the future in terms of switches and tracks. The challenge is to define a topology which meets all operational requirements today and in the future since the renewed infrastructure should last for 50 years or even more. As an input for this planning task only the relations of train services are well known. The timetable for each train service might be still open but at least the frequency of services will be defined. Of course, in the future an increase of services might be required. Therefore, the topology should allow conflict free operation of all kind of services. Another important parameter is the minimum headway between different services which can be simulated by software tools like OpenTrack [1]. In this paper we assume short blocks with ETCS Level 2 to achieve headways of less than two minutes [2]. State of the art methods for analysis of station layouts are described in [3] and inspired this paper as well.

2. REQUIRED CONNECTIONS

Figure 1 shows all railway lines joining station Resnik. On the left side, there is one double track line with InterCity (IC), Regional (R) and S-Bahn (S) services. Note, that the S-Bahn service is starting and ending in station Resnik. Also on the left side there is a single track line only used for cargo trains (GZ). On the ride side, there are two double track lines with mixed operation as well. This figure is now the starting point for the development of different infrastructure topologies.

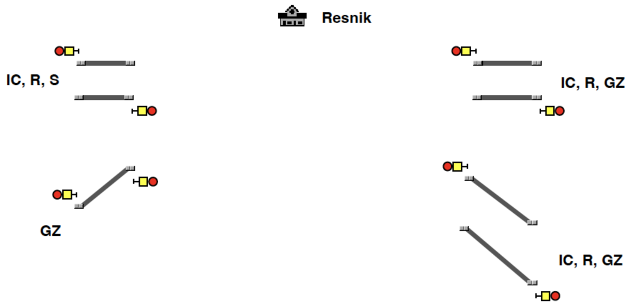

Fig.1. Boundary conditions for station Resnik

3. DEVELOPMENT OF DIFFERENT INFRASTRUCTURE TOPOLOGIES

The first scenario of infrastructure layout is the minimal layout. Therefore, number of switches and station tracks is minimized. All required connections are established. Switches at the right side of the station allow parallel running of trains in same or opposite direction. In this scenario the turning S-Bahn service is blocking one track while the driver is changing cabin. As a benchmark criteria the number of required switches is only 11 with only 3 station tracks. For the maintenance budget this scenario is definitely interesting and worth to be considered. Of course, crossing train paths lead to operational conflicts. Therefore, the application of this layout is limited by the traffic density even if switches allow same speed for diverging branches like for the straight option.

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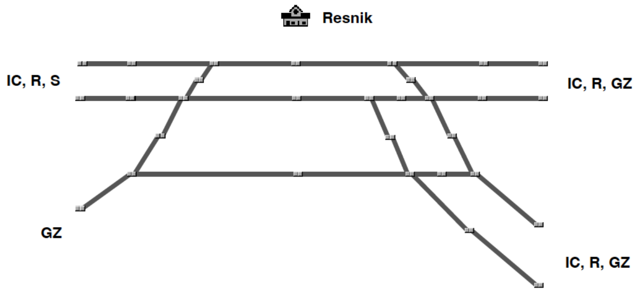

Fig.2. Minimal layout

For highly frequented lines a conflict-free layout with bridges and tunnels is the better solution to prevent operational conflicts simply by design. A solution is presented in figure 3. This topology allows parallel operation on all double track relations while sorting in and out of cargo trains on the left side is possible without operational conflicts as well as on the right side for fast trains (IC) and regional trains (R). The turning local service S-Bahn has its own track and is therefore not blocking any stopping or passing train. 12 switches and 4 station tracks are required in this layout.

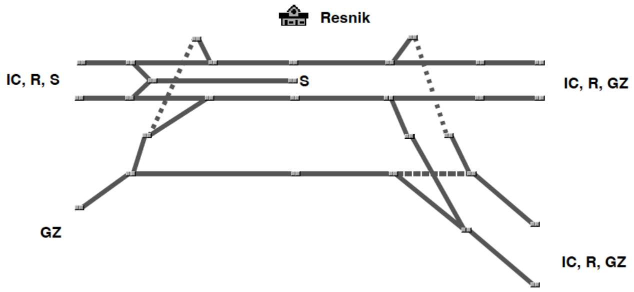

Fig.3. Conflict-free layout

Of course, there might be an additional requirement for the design of s station to store cargo trains. There might be also an operational reason for such a break like change of driver or any other logistical reason. Another reason could be the capacity of the lines. This would also justify to have additional station tracks for cargo trains. This offers the opportunity to split the station into a passenger and a freight part. This layout is presented in figure 4. In figure 4 three tracks have been added for storing cargo trains. Of course, this number can be extended upon request. To conclude, this scenario requires 15 switches and 6 station tracks

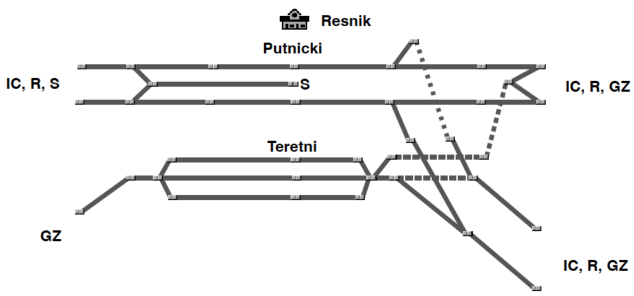

Fig.4. Design by function layout

To allow passengers to change trains in station Resnik at least two additional station tracks are required. The extension is presented in figure 5. For the passenger part of the station the direction based approach was chosen. The other option would be the line based approach which could be interesting for passengers turning direction of travel in Resnik. Since the majority of passengers will be interested in Belgrade, this option is less worth to be realized. The overall number of switches is still 15 but now with 8 station tracks.

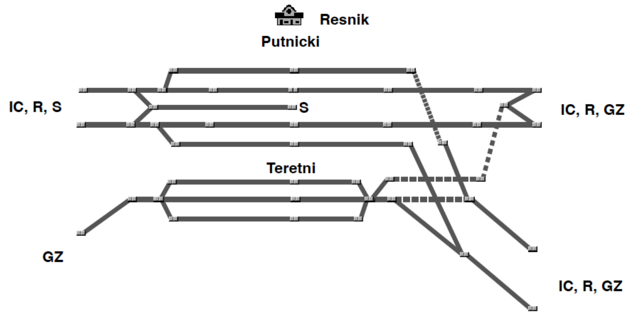

Fig.5. Extension for passenger change

After these several extensions one might ask to reduce again complexity of the topology. If we agree to mix passenger and cargo trains again, all trains can use the same tracks in stations. This approach can be used when track speed limit is not too high. As long as we are not operating high speed trains, this approach can be a good solution.

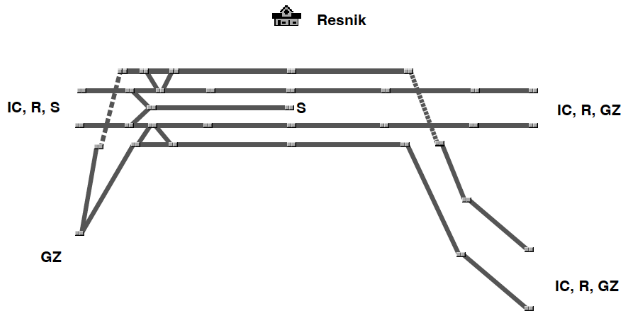

Fig.6. Another Simplification

Figure 6 shows this simplification of the topology. Unfortunately, the switches do not allow conflict fee operation of cargo trains and InterCities (IC) although the overall number of switches is now 12 with 5 station tracks. To solve these conflicts another solution is proposed in figure 7.

This scenario requires 12 switches and 7 station tracks to allow conflict-free operation in all relations. Of course, it might take some time to convince traditional railway engineers to investigate this layout during the planning procedure but it looks promising in terms of life cycle costs and operational performance.

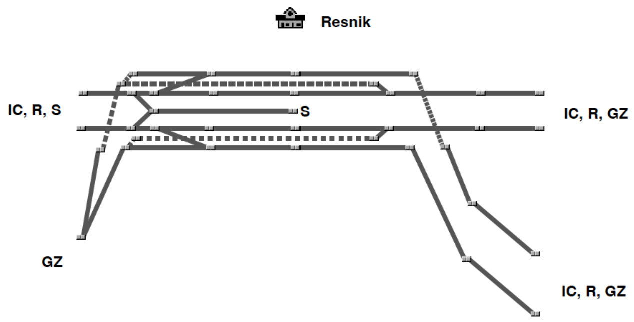

Fig.7. Final proposal

4. CONCLUSION

The development presented in this paper for the design of a railway station topology shows the complexity of requirements. Taking into account the life cycle costs for all infrastructure assets like switches and station tracks as key parameters the topology must definitely meet the operational requirements on one hand but on the other hand it should be also efficient in terms of maintenance. For further investigation only conflict free layouts should be considered in the planning process. Of course, the argument is well known that if you have the chance to rebuild a station you should foresee possible extensions which might be required in the future. The answer is coming from the minimum headway times. By application of a microscopic simulation tool the planner can simulate if the number of station tracks is sufficient or not. Obviously, the stopping pattern of trains has a strong impact on this result. Less stopping requires less station tracks. This rule is valid for passenger trains as well as for cargo trains. Additionally, the dwell time is a crucial parameter for the possible headways and thereby strongly influencing the capacity of stations.

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ANALYSIS OF RAIL TRANSPORTATION SERVICES FROM THE ASPECT OF PERSONS WITH DISABILITIES: SECTION BELGRADE-NOVI SAD

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Abstract *– Pointing out and emphasizing the necessity of supporting persons with disabilities when using rail transportto increase the level of service provided, accessibility, and mobility for this demographic group in the Republic of Serbia is considered another necessary step for a better society. With the questionnaire related toservices in passenger rail transport, it is possible to receive the feedback from passengers on various aspects of train journeys and railway station utilization. The goal of the questionnaire is to provide railway operators with insight into the attitudes and needs of passengers so the service quality and travel experience could be improved. The presentation of such results is very important not only for persons with disabilities but also for wider professional audiences and decision-makers to identify deficiencies with the performed works on the railway infrastructure, thereby enabling improved problem-solving strategies and preventing the recurrence of similar issues at other locations.*

Keywords – Persons with disabilities, service, railway, satisfaction

1. INTRODUCTION

People with disabilities mainly use road transport services to fulfill their daily or periodic needs. They use rail transport services far less, primarily due to the inadequacy of the quality of the service provided, although rail transport has known comparative advantages.

In the Republic of Serbia, there are certain activities aimed at improving the social inclusion of persons with disabilities by looking at possible steps in solving the problem of accessibility to all public railway facilities.

Travels made and services provided directly affect mobility limitations, which can be psychological, social and psychophysical. It is for these reasons that issues of overcoming possible limitations and ensuring the greatest possible mobility and access to all desired destinations are being raised [1].

Realization of the rights of persons with disabilities in the areas of social, health, family - legal protection, employment, traffic, etc. it is regulated by laws and other regulations. These documents can be of international or national character.

Knowledge about persons with disabilities and public transport is imposed as a need for their better understanding. As a result of the research, it was determined that it is not easy to get to the bottom of the needs of people with disabilities because some of them have no idea what kind of environment there is, while on the other hand, there is a larger number of them who have personally experienced inaccessible transport [2].

This research aims to understand the experiences of PWDs (people with disabilities), including those who do not use rail transport. Data were collected from PWDs with various disabilities, focusing on the satisfactory services offered in stations and trains.

2. LITERATURE OVERVIEW

Understanding the activities and dynamics of the behavior of certain populations and better identifying the satisfaction of their needs for future planning of the system is put as a postulate to which attention should be paid [3]. The needs and requirements of PWDs differ depending on the type of disability and the needs of these people for public transportation,

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due to the collection of the highest quality data in the paper [4], the information is viewed according to availability and reliability in real time.

In order to obtain complete information, it is necessary to collect travel patterns and attitudes of people with disabilities and consider the problems they face in different modes of transport [4], [5]. The availability of transport service and the possibility for people to be mobile is not equally distributed among all social groups, it was stated in [6].

As one of the examples of individual research, the study of blind and partially sighted people is presented in paper [7]. The main characteristic of this research is that it is not necessary to improve physically, but rather the way and type of information that would be available to them.

At the end of the 20th and the beginning of the 21st century, a number of documents were adopted in the EU that looked at the improvement of the development of transport. Accordingly, and the possible unification of the observation of both problems by the introduction of standards [8], the approach to the operation of public transport was promoted with a focus on the needs of users and their expectations.

From 2021 to 2023, the accessibility of facilities for persons with disabilities in wheelchairs is being analyzed on parts of the reconstructed railway network of the Railway Infrastructure of Serbia. In the papers [9], [10], [11], conducted only on the main corridors of the Rakovica-Resnik and Belgrade center – (Novi Sad station - excluded) line indicates that individual measures have been implemented, but access to all facilities and independent access to the platform for people in wheelchairs is not fully provided.

3. STUDY AREA AND METHODOLOGY

3.1. Methodology

The regular surveys on population mobility conducted in the Republic of Serbia do not adequately address traffic needs for PWD population. This study represent ongoing support for better understanding problems that PWD face in railway traffic. All questionnaires were submitted to associations, which were later sent by e-mail or personally handed over to the respondents. The study participants had various disabilities.

The surveyed population covered urban and rural areas within the Republic of Serbia over railway section Belgrade-Novi Sad. The questionnaire was divided into three parts: Demographic characteristics of the respondents, including municipality of residence, gender, age, and work status (employed, dependent, pensioner), Satisfaction with the services in the stations, Satisfaction with train services.

Due to the importance of this research and the comparability of the obtained results with other European countries, adapted questions from the Eurobarometer, the SRPS EN 13816:2012 standard and positive practices in the field were used as the basis for this questionnaire.

3.2. Study Area

To assess passenger perception, data was collected through a questionnaire survey about Serbian Railway Network, section Belgrade center – Novi Sad, shown in fig. 1.

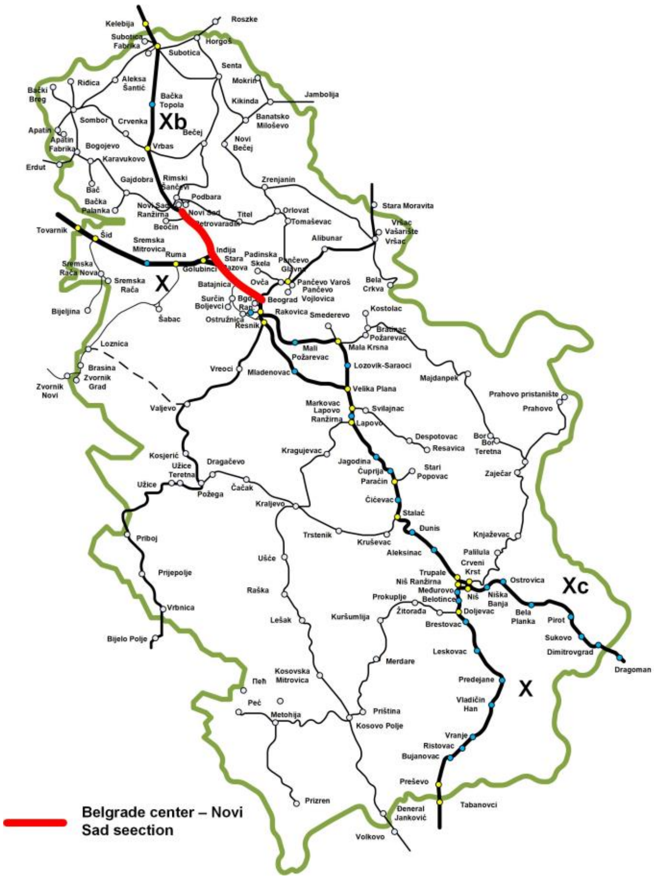

Fig.1. Observed railway section

4. RESULTS

This study involves 25 respondents from the PWD population, and the data was collected through a questionnaire survey conducted from April 1st, to June 25th, 2024. Despite the best efforts of individuals and associations, reaching the PWD population was a challenge, and the maximum possible number of respondents was collected.

4.1. Socio-demographic characteristics

The classification of the PWD population was based on the collected databases.

Tab. 1. Socio-demographic characteristics

No.	Characteristics	Frequency	Percent
1.	**Gender**		
1.1.	Man	11	44
1.2.	Women	14	56
	Total	25	100
2.	**Age**		
2.1.	15-20	4	16
2.2	21-25	1	4
2.3.	26-30	2	8
2.4.	31-35	2	8
2.5.	36-40	3	12
2.6.	41-45	5	20
2.7.	46-50	2	8
2.8.	51-55	3	12
2.9.	56+	3	12
	Total	25	100
3.	**Mobility**	**Frequency**	**Percent**
3.1.	He uses a wheelchair, another person drives	2	8
3.2.	He walks with the help of aids	4	16
3.3.	He walks with the help of another person	4	16
3.4.	Uses a wheelchair, drives independently	5	20
3.5.	Walks independently	10	40
	Total	25	100
4.	**Speech**	**Frequency**	**Percent**
4.1.	Doesn't speak, but he communicates	1	4
4.2.	Normal	23	92
4.3.	Not very difficult, understandable	1	4
	Total	25	100
5.	**Education_level**	**Frequency**	**Percent**
5.1.	Faculty or higher school (academy)	17	68
5.2.	High school	6	24
5.3.	Primary school	2	8
	Total	25	100
6.	**Working status**	**Frequency**	**Percent**
6.1.	Dependent	5	20
6.2.	Employed	15	60
6.3.	Pensioner	5	20
	Total	25	100

4.2. Railway users

This question is very important because previous research has shown that, unfortunately, a considerable number of PWD population, i.e. 40% do not use the railway. The main reasons given by respondents are lack of information regarding accessibility and general service, lack of specific staff.

4.3. Satisfaction with the services

In order to view the satisfaction responses from the survey, an overview is presented based on the most significant responses, as follows: Very dissatisfied (VD), Dissatisfied (D), Neither satisfied nor dissatisfied (NSD), Satisfied (S), Very satisfied (VS).

The main and sub-groups present all the answers related to station area and trains.

Satisfaction with the services in the stations

ARRIVAL - STATION SQUARE: Connection with public transport (S), Parking spaces (NSD).

SERVICES: Quality of service in the facility (toilets, shops, cafes) (NSD) and (S), Availability of free Wi-Fi (NSD) and (S), Mechanism for dealing with complaints (NSD), Customized care for users who need medical assistance (NSD).

INFORMATION AND MOVEMENT: Information on timetables and reservations (S), Easy orientation and movement through the station (S) and (VS), Simple notice boards with information and instructions (D) and (VS), Accurate and clear information about the tracks on which the train is located (S), Information in case of train delays or cancellations (VS).

TICKETS: Ticket price (VS), Ease of purchase (S) and (VS), Ticket purchases according to different tariffs (S), Different payment options (S), Format and information on the ticket (VS).

COMFORT: Comfort of benches in waiting rooms and on platforms (S), Comfort and adaptability of rooms for mother and child (NSD) and (S), Air conditioning in the facility (S).

SECURITY: Personal security (S), Additional security personnel (S), Installed video surveillance (NSD).

STAFF: Existing Station Staff (S), Additional Support (S), Staff Positive Staff Attitude (S).

CLEANLINESS: keeping the pedestrian corridors and platforms clean (S), keeping the toilets clean (NSD).

Satisfaction with train services

TRAINS: Number of train departures (S), Travel time and speed (S), Punctuality and reliability (S).

SERVICES: Quality of service on the train (S) and (VS), Availability of free Wi-Fi (NSD) and (S), Availability of mobile signal (S), Serving coffee, drinks and food (S).

INFORMATION: Provision of information during the journey (S), Clear and accurate information during the journey (S).

COMFORT: Sufficient number of seats for passengers (VS), Comfort seats or places for wheelchairs (S), Air conditioning in the train (S), Luggage space (VS).

SECURITY: Personal security (VS), Additional security personnel (VS), Installed video surveillance (VS).

STAFF: Availability of staff on the trains (S) and (VS), Help and information provided (S), Positive attitude of the staff on the train (S).

CLEANLINESS: Maintenance and cleanliness of trains (S) and (VS), Maintenance and cleanliness of toilets on the train (NSD).

5. CONCLUSIONS

The main reason for respondents not using the railway is a lack of prior information about accessible services, which is 55%.

In the area of the station in the main group Services - and subgroup Mechanism for handling complaints according to 60% of respondents, it is considered that improvement can be made. Furthermore, in the open answers, the most significant items that can be improved include the impossibility of booking a ticket with privileges, more information for the blind and partially sighted in the station and and improving accessibility from public transport stops to the train station.

In the trains in the main group Maintenance and cleanliness - and the subgroup Cleanliness in tolets according to 40% of respondents, it is considered that it can be improved. Furthermore, in the open answers, the most significant items that can be improved are for the blind and partially sighted direct communication with the service to provide support in relation to everything needed on the train.

Although there is a lot of progress in improving the position of PWDs, it can still be said that these people "suffer" a certain degree of discrimination because they are not provided with full mobility, which can be limited even with the services provided.

As the next step of this research, it is necessary to animate a larger number of respondents in associations of PWDs due to a larger sample, and mandatory education and presentation of the reconstructed section of the railway lines.

In parallel with the collection of data, it is necessary to carry out additional education for both students and engineers who plan, design and perform works, as well as executive authorities and traffic service providers.

ACKNOWLEDGEMENT

This paper is part of the author's long-term research regarding PWDs and railway traffic. In this research, we would like to express our special gratitude to the associations of PWDs in the Republic of Serbia and their members, without whose help it would not have been possible to write this paper.

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COMPARATIVE ANALYSIS OF TRAIN TRAFFIC USING SIMULATION MODELS

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Abstract *– Trains move in a specific way, along a pre-determined path, i.e. rails. The wheels of railway locomotives and rails are steel, and because of this, it is possible to achieve very high speeds, with relatively low resistance to movement. Analysis and research related to the movement of trains are very important from many aspects, especially for traffic safety. In this paper, a simulation of train movement under realistic conditions was performed. The simulation was created using the Python programming language. Infrastructure data, locomotive data, and resistances were used as input data, which Python later converts for simulation. The results of the simulation are presented both graphically and numerically. All data used in the Python simulation model was also input into the verified railway simulation software OpenTrack. The results from both tests were compared and analyzed, and a report was generated on the feasibility of using the created program in real-world scenarios.*

Keywords – traction, braking, simulation, open track.

1. INTRODUCTION

Railway systems involve significant expenses during both construction and operation. From this perspective, it is essential to build a system without deviations or to minimize them to an acceptable level. Creating realistic conditions under which the railway system can be tested is challenging and usually unprofitable. Therefore, simulation models are necessary to predict and analyze various operational scenarios before the actual construction and implementation of the railway system.

Simulation models allow engineers and planners to evaluate the system's performance under different conditions, identify potential bottlenecks, and optimize design choices without incurring the high costs associated with physical testing. These models can simulate various factors, such as train speed, track resistance, signal systems, and interactions between trains and infrastructure. By utilizing simulation models, engineers can assess how the railway will perform in real-world conditions, ensuring that all critical parameters are met. This approach enables more efficient planning, helps avoid costly adjustments during or after construction, and ensures that the final system operates smoothly within predefined safety and performance limits.

The theory of traction studies the basics and methods for calculating traction to determine the optimal conditions for train movement. The basic elements of traction theory in railway track design provide a foundation for defining the movement characteristics and regimes of a train on the projected route. To perform a traction calculation in simulation models, it is necessary to identify the forces acting on the train during movement and define the conditions of train movement. To simplify the calculation while maintaining a certain degree of accuracy, the train's mass is assumed to be concentrated at its center of gravity, with a mass corresponding to the total mass of the train. During train movement, the following external forces act on the train [1]:

- Traction force
- Resistance to movement
- Braking force

The values implemented in the simulation should be derived from the list above. Additionally, the formulas used to calculate train movement should be recognized and scientifically validated. These formulas may vary across different countries due to differences in

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equipment and technology used.

Simulations can be developed using various programming languages, but the core results remain consistent across platforms, with differences arising mainly in efficiency, scalability, and user interface designs.

2. MODELLING IN PYTHON

Modelling of train movement consists out of four parts:

1. Forming basic formulas for train traction,
2. Integrating these equations with topology and resistance data,
3. Calculating train braking,
4. Representing the results graphically.

The specific active traction force is the force that remains after subtracting the resistances from the tractive effort, and it is used for train acceleration:

$$F_{va} = F_v - W \text{ [daN/t]} \quad (1)$$

Where:
F_v – traction effort,
W – resistance force.

If the active traction force is greater than zero, the train is accelerating. If the active traction force equals zero, the train is moving at a constant speed. If the active traction force is less than zero, the train is decelerating. The traction force is calculated from the tractive effort diagram using the equation of a line through two points:

$$y - y_1 = \frac{y_2 - y_1}{x_2 - x_1}(x - x_1) \quad (2)$$

Figure 1 below illustrates the traction effort.

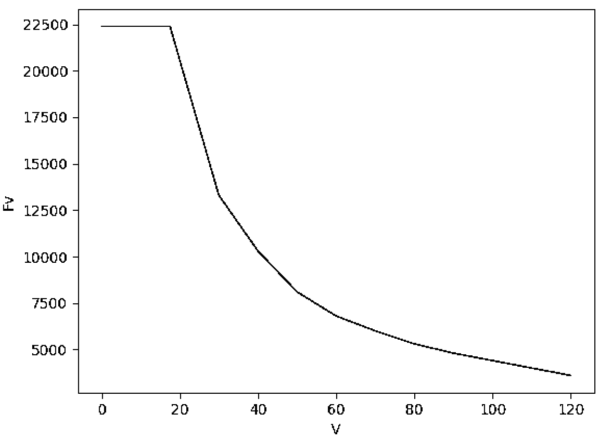

Fig.1. Tractive effort diagram

The resistance of the locomotive was also calculated using the same formula. For each speed range, there is a corresponding value of resistance and traction force. For railway wagons with rolling axle bearings, the following formula is used to calculate specific resistance [2]:

$$w_{ok} = 2.2 - \frac{80}{V+38} + (k + 0.007) \cdot \left(\frac{V}{10}\right)^2 \text{[daN/t]} \quad (3)$$

Where:
k - coefficient that depends on the type of wagon,
V – current speed

Temporary resistances acting on the train include slope resistances and curvature resistances. Tunnel resistances have not been included. The specific resistance of a slope is defined as:

$$w_i = i \text{ [daN/t]} \quad (4)$$

Where:
i – gradient in ‰.

The analytical expression for calculating the specific curvature resistance for curves with a radius greater than 272 meters is:

$$w_k = \frac{650}{R-55} \text{[daN/t]} \quad (5)$$

Where:
R-radius of curve in meters.

After defining the temporary resistances, the next step is to calculate the fictive slope. This involves calculating the resistance of each individual curve (or just a segment of the curve) located on the observed gradient. Sum all the resistances from the curves and transfer the data to the fictive slope resistance. The resistance of the gradient section w_{i1}, with curve resistance w_{k1} on it, is equal to the resistance of the gradient without the curve w_{i2}, where:

$$w_{i2} = w_{i1} + wk_1 \text{ [daN/t]} \quad (6)$$

By combining all the given formulas, the calculation of small increments in time and distance is achieved, with speed as a variable parameter. The speed value is increased by 0.1 km/h for each case. The time increment is defined as:

$$\Delta t = \frac{\Delta v}{2\cdot(|F_{va}(v)| + \frac{|F_{va}(v+\Delta v)|}{2})} \text{ [s]} \quad (7)$$

Where:
$F_{va(v)}$ - Specific active traction force for initial speed
$F_{va(v+\Delta v)}$ - Specific active traction force for the initial speed with a speed increment

Distance increment is defined as:

$$\Delta l = \frac{(2\cdot v + \Delta v)}{2} \cdot \Delta t \text{ [m]} \quad (8)$$

Where:
v- starting speed
Δv – speed increment
Δt – time increment

Once the speed reaches the maximum value input by the user, or the train reaches the last point where brakes are applied - regardless of whether the maximum speed has been reached - the calculation stops. The sum of all small distance increments represents the total distance traveled from the start to the braking point. Similarly, the sum of all small time increments represents the total travel time from the start until the train reaches the braking point.

After reaching the braking point, the next step is calculating the braking distance. Braking Distance is the distance the train travels from when the train driver makes a full-service brake application to when the train stops [3]. Braking distance small increment calculation include:

$$\Delta l = \frac{4.13(v_{1+\Delta v} - v_1)}{\mu \cdot \delta \cdot \beta + w_{okavg} + w_{i2}} \text{ [m]} \quad (9)$$

Where:
$v_{1+\Delta v}$ – initial speed with speed increment,
v_1 – initial speed,
μ – adhesion coefficient,
δ – braking weight percentage,
β – pressure coefficient,
w_{okavg} – average specific resistance of railway wagons between the initial speed and the initial speed with increment,
w_{i2} – fictive gradient resistance

The distance for which the brake pressure is fully developed must be included, along with the distance the train travels during the driver's reaction time. This is calculated using the basic formula for distance traveled over time at a given speed. The final step involves generating graphical speed/distance curves, which represent the total distance covered during acceleration, any constant speed phase (if applicable), brake preparation distance, and braking distance.

3. INPUT PARAMETERS

The input parameters include all variables used in the equations. For testing the model, infrastructure data from mainline track number 109, covering the section from station Batočina (km 3+405) to station Jovanovac (km 22+335), was utilized. Locomotive data was sourced from the tractive effort diagram of locomotive 661. Remaining variables were directly entered into the Python environment for calculation.

4. TESTING PYTHON MODEL

Two tests were conducted using the Python model, and the results were later compared with Open Track. Below are the input data for Python Test 1:

- Speed: 80 km/h
- Train mass: 1000 t
- Braking weight percentage: 100%
- Adhesion coefficient: 0.14
- Speed increment: 0.10 km/h
- Pressure coefficient: 5.60

Python 1 output data:

- Distance to braking point: 18 286 m
- Time to braking point: 18.81 min
- Braking distance: 589 m
- Braking time: 0.69 min
- Braking point speed: 73 km/h
- Constant speed distance: 0 m

The following figure 2 shows the output.

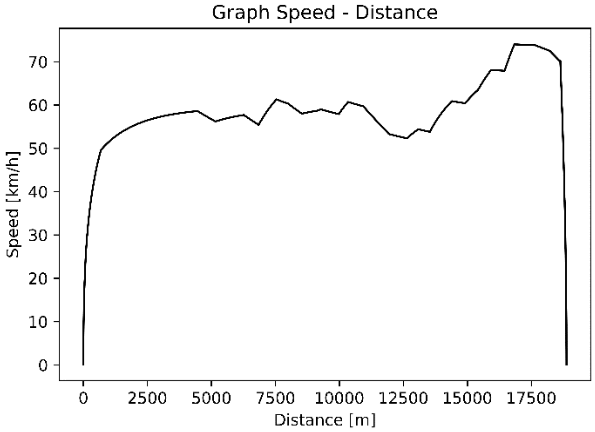

Fig.2. Python test 1 - speed/distance graph

Python test 2 input:

- Speed: 80 km/h
- Train mass: 600 tones
- Braking weight percentage: 100%
- Adhesion coefficient: 0.14
- Speed increment: 0.10 km/h
- Pressure coefficient: 5.60

Python test 2 output:

- Distance to braking point: 18 164 m
- Time to braking point: 15.20 min
- Braking distance: 711 m
- Braking time: 0.77 min
- Braking point speed: 80 km/h
- Constant speed distance: 2 752 m

The following figure 3 shows the output.

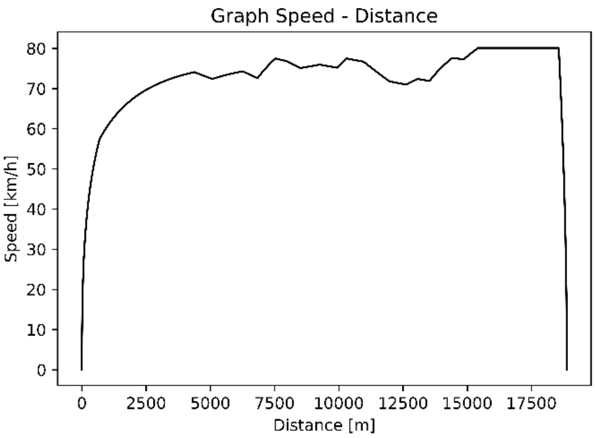

Fig.3. Python test 2 - speed/distance graph

5. TESTING OPEN TRACK MODEL

The testing in Open Track utilized the same parameters as the Python model to ensure consistent comparison. All necessary data were included, and the OpenTrack Test 1 output data is as follows:

- Distance to braking point: 18 322 m
- Time to braking point: 18.97 min
- Braking distance: 553 m
- Braking time: 0.61 min
- Braking point speed: 73 km/h
- Constant speed distance: 0 m

The following figure 4 shows the output.

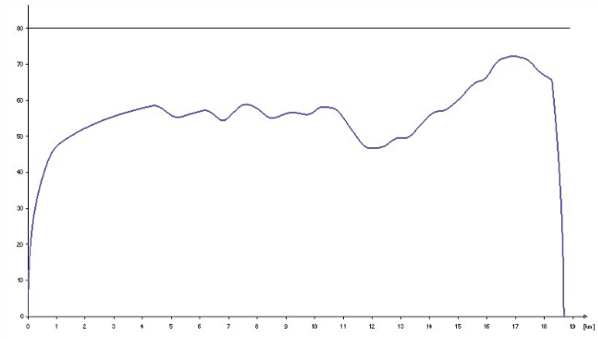

Fig.4. Open Track test 1 - speed/distance graph

Open Track test 2 output data:

- Distance to braking point: 18 207 m
- Time to braking point: 15.64 min
- Braking distance: 668 m
- Braking time: 0.70 min
- Braking point speed: 80 km/h
- Constant speed distance: 2 766 m

The following figure 5 shows the output.

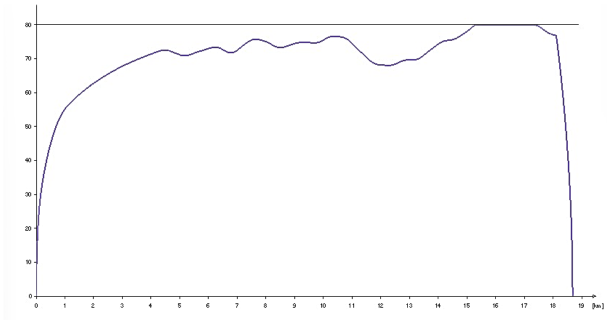

Fig.5. Open Track test 2 - speed/distance graph

6. CONCLUSION

The core objective of this research is to accurately approximate the movement results of a railway vehicle, aiming to determine the maximum thresholds the train can reach during the design phase. The accuracy of the data obtained from this program was validated through a comparative analysis with data from OpenTrack. The program demonstrated a high degree of precision, despite some resistances being omitted. The models illustrate how changes in one parameter affect the train's movement. By incorporating additional parameters, the program would depict the train’s movement along the section with substantially higher accuracy. This model serves as a tool for engineers, enabling them to estimate key data without needing to create complex datasets.

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IMPROVING CYBER SECURITY IN RAILWAY TRAFFIC AND TRANSPORT USING BLOCKCHAIN TECHNOLOGY

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***Abstract** – Today, the management of railway traffic and transport is mainly based on the application of computer hardware and software components that are installed in the company's official premises. The application of information and communication technologies (ICT) includes all processes that take place in electronic business between employees, citizens, as well as between machines and devices, indirectly or directly. The improvement of business operations of companies with a tendency to grow and the application of digital infrastructure implies the use of protective mechanisms that prevent cyber attacks and threats. Cyber attacks in such complex business processes (the security of traffic regulation from dispatch centers and even to digital money transactions when buying a ticket or paying for the transportation of a shipment) can cause malicious activities from unknown attackers in order to redirect or modify messages. Basically, it is necessary to apply measures to protect connected computer systems, which include signaling, control, mutual communication and the safety of all traffic participants. This paper presents a model of protection, cyber security in the railway company, which implies the application of blockchain technology as today's most powerful mechanism for storing and memorizing data in digital processes.*

Keywords – railway security, ICT, cyber attacks and countermeasures, data protection in digital processes, block chain technology.

1. INTRODUCTION

This paper presents a mechanism for improving cyber security using block chain technology. The basis is a large number of operations that take place in various digital processes, from the exchange of emails between employees to the regulation of traffic from dispatch centers. In addition to the above, service users have the opportunity to satisfy their needs for purchasing and receiving services through the available computer components. The application of innovative technologies is increasingly prevalent both among users and among railway carriers [1],[2]. Block chain is currently one of the safest protection mechanisms [3],[4]. In the following, the available literature will be analyzed where researchers have various approaches in solving problems related to increasing cyber security in railway traffic and transport. The application of information technologies will improve the current protection mechanisms [5]. The paper includes a description and graphic representation of the functioning of block chain technology, which has yet to be implemented in the railway company.

2. RELATED RESEARCH

In practice, there is a large number of works dealing with cyber security in railway traffic. For the purposes of this work, some were selected from which one can see the importance and specificity of the need to protect data that is exchanged in increasingly complex computer systems. The modern development and regulation of railway traffic also implies the application of advanced Internet technologies, which, through a detailed analysis, can have certain disadvantages in addition to great advantages.

Technological advances in the telecommunications industry have brought significant advantages in the management and performance of communications networks. The rail industry is among those that have benefited the most. These interconnected systems, however, have a wide area exposed to cyber attacks. The author's research [6] examines the cyber security aspects of railway systems by considering the standards, guidelines, frameworks and technologies used in the industry to assess and mitigate cyber security risks, particularly in terms of the relationship between security. To do this, special attention is paid

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to signaling, whose fundamental reliance on computer and communication technologies allows us to better explore the multifaceted nature of safety in modern hyper-connected railway systems. With this in mind, it then moves on to analyze the approaches and tools that practitioners can use to facilitate the cyber security process. In detail, a view of cyber ranges is presented as a technology that enables the modeling and emulation of computer networks and attack defense scenarios, the study of the impact of vulnerabilities, and ultimately the design of countermeasures. It also discusses several possible use cases that are strongly related to the reality of the railway industry.

With the deepening and implementation of China's network power strategy, critical information infrastructure has become increasingly prominent in social development. China's national cyber security strategy proposes protecting critical information infrastructure. In addition, it also declares that nationally critical information infrastructures include information infrastructures related to national security, national welfare and human life. When critical information infrastructure is damaged or partially functional, which may seriously threaten national security and public interests. It is vital to protect critical information infrastructure from damage. Currently, it is necessary to improve the risk assessment system of critical information infrastructure. For critical information infrastructure, there is a lack of a risk assessment method, which is an assessment of the effectiveness of security measures. In order to meet the requirements for ensuring the security of critical information infrastructure, a statistical risk assessment model is set up and a risk assessment method based on the fuzzy analytical infrastructure hierarchy (AHP) process for critical information is proposed. In this paper, the proposed risk price is evaluated in a practical system and the proposed estimation method is also verified [7].

In order to raise the level of automation and information, a large number of common information technologies are applied to railway signaling systems, which leads to an increase in the openness of signaling systems and an increase in security risks. Quantifying the effects of safety risks is an urgent task, which is a major challenge for railway signaling systems due to the lack of safety metrics and an effective assessment approach. In the author's work [8], based on service characteristics and cyber-physical characteristics of railway signaling systems, a resilience-based safety assessment approach is proposed to describe performance changes during different phases of safety events, which can illustrate signaling robustness and recovery capability. systems facing cyber attacks. Considering a typical scenario where malicious jamming attacks are applied to train-ground wireless communications, the proposed security assessment approach shows the security levels of railway signaling systems. Based on the time variation of the resilience indicator, a cognitive control strategy is developed to improve the overall performance and resilience of the signaling system. The simulation results demonstrate the validation and effectiveness of the proposed safety assessment approach.

A simulation of a modern railway system at a cyber range will explore the flexible behavior of cyber-attacks in a modern digital railway system. Modern railway digital simulation architecture will focus on railway signaling system and control command system, which is a classical SCADA system. With the introduction of IoT technology in railway systems, they have become vulnerable to cyber attacks. The simulation is conducted on a cyber range server by simulating STCS. Cyber threats were analyzed through penetration testing using Kali Linux on a simulated STCS at the cyber range. The impact of groups of threat agents is analyzed, especially denial of service (DoS) and key chain attacks that mainly target STCS. A DoS attack generates packet congestion in the railway system network and compromises the SCADA components in the STCS. The quay chain attack compromises the SCADA component, leading to delays in the STCS signaling system. Attack tree analysis helps to understand the behavior of threat agents on STCS. Based on the research, some mitigation techniques have been identified to reduce the impact of cyber attacks on the modern digital railway system [9].

3. DEVELOPMENT OF A MODEL FOR INCREASING CYBER SECURITY IN THE RAILWAY COMPANY

3.1. The basics of cyber security

Since a large number of activities involving the exchange of messages between devices or people take place in the railway company, there is a potential danger of cyber attacks. In practice, network security means protecting the network from potential unauthorized access, where only authorized users can access the network directly, and of course all messages passing through the network are encrypted. Today, there are four types of network security that show good results:

- A firewall that is intended for traffic control between networks AND at the same time protection against connection threats and potential attacks,
- Network segmentation where the network is divided into smaller segments and can increase the security of isolated individual parts,

- Virtual private networks include secure access to the network but only to certain users,
- Email protection, which includes encryption, authentication and at the same time the protection of the software as well as the user.

In contrast to the above, cyber security is a broader concept that includes all aspects and that:

- Training of end users who perform various tasks,
- Ensuring uninterrupted operation when a problem is established or a part of the computer system is damaged,
- Operational security, which includes security in IT operations and digital transactions,
- Information security, which includes information management operations in a secure manner where privacy is guaranteed,
- Security at the application layer where available applications are used,
- Network security where different types of protection are defined in advance.

Solutions to potential problems are in block chain technology, which today is the most reliable mechanism for storing and distributing data in a safe and secure way. The main advantage of block chain is decentralization as well as high resistance to potential attacks.

In the continuation of this work, an innovative model of application of block chain technology in railway traffic is presented.

3.2. Block chain protection mechanism to increase cyber security

Complex computer systems are responsible for a large number of operations that can occur simultaneously. Each digital transaction represents one record. Block chain represents a series of chronologically sorted records that are organized into blocks and linked and protected by cryptography. Each block is formed in the same way and contains a cryptographic hash code, a timestamp and information about the transaction itself. A hash code is the result of a mathematical function of transforming an input of arbitrary length into an encrypted output of fixed length and is a basic tool of modern cryptography. This function is unidirectional or in other words, there is no reverse algorithm by which to get from the hash code to output, received the original input data. Cryptographic hash functions have a large application in applications in the domain of security and digital signing of data, so is their application in block chain platforms one of the bases of security and immutability of transactions. In addition to its own hash, each block also contains a hash code of the previous block, thus guaranteeing the integrity of the data, because any subsequent modification would of data in the block chain required the modification of all previous blocks. In Figure 1 it is given showing the basic architecture of the block chain network.

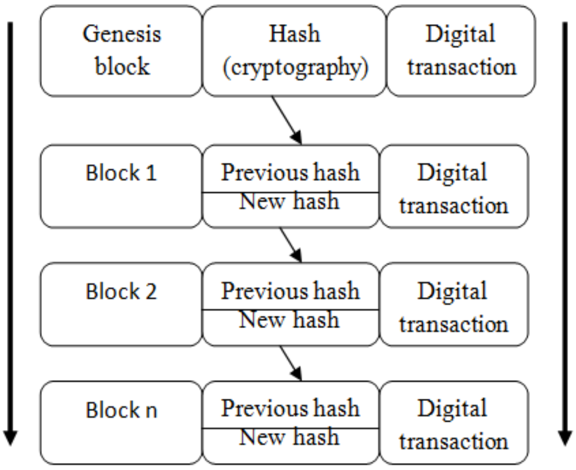

Fig.1. Block chain architecture

An example can be the functioning of the block chain in the railway company shown in Fig. 2.

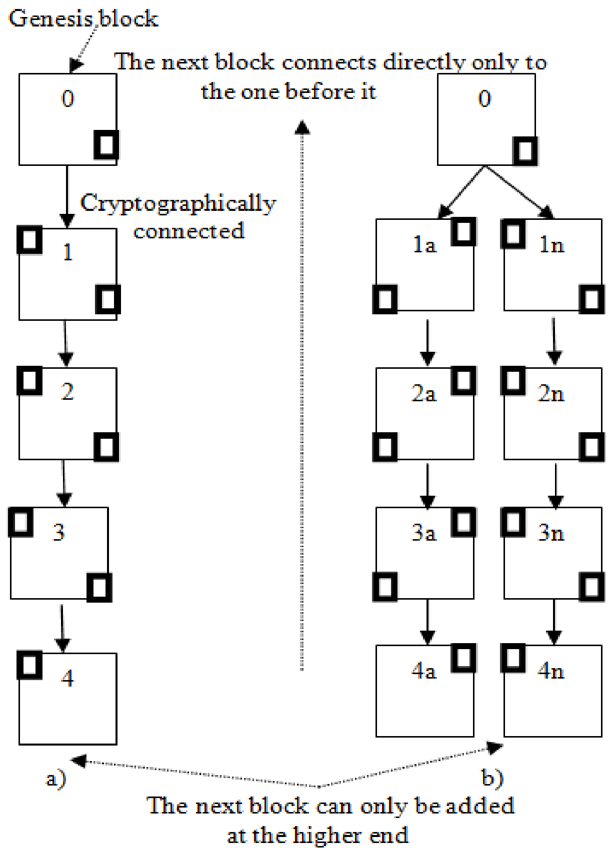

Fig.2. Structure and branching of blocks [3]

All transactions that take place in the network can be linear or branching. In the first case (under a), a linear sequence of blocks containing data on exchanged messages from the departure of the train to the arrival at the destination station is displayed. It can be seen that each block has its predecessor and its successor.

The application of block chain in the manner shown provides storage of a large amount of data related to the exchange of all messages in the form of orders, instructions, notifications, as well as all other processes that take place digitally. Block chain technology secures the mentioned activities from cyber attacks and increases security at the same time. The available hardware and software capacities have the possibility of upgrading in order to improve safety in railway traffic and transport.

There are numerous platforms for the application of block chain, which at the same time enable:

- The speed of the block chain enables a large number of transactions per second,
- Block chain network can be public or private. In this work, a combination of private and public networks is recommended, the private network is used in large companies where only employees and partners who are allowed to participate in transactions can participate. And on the other hand, a public network allows individuals to use block chain technology for their security.
- The security of the block chain is guaranteed by cryptographic techniques and algorithms that require the connection of 50% plus one computer in the world in order to organize a good attack, which is not feasible in practice.

4. CONCLUSION

This paper shows the possibility of implementing the innovative block chain technology, which is based on computer equipment and a network in order to protect digital messages that are exchanged in business processes. With the increase in the use of block chain, the importance of the scalability of that system is gaining importance as well as its application in other companies. Block chain technology can accommodate new applications and a large number of transactions, but this requires changes and the addition of new software technologies to maximize throughput.

In the current and future operations of the railway company, it is understood that operations are based on the management of the protection system where mutual trust is created between interested parties. Block chain technology provides an innovative approach to the remodeling of the railway traffic and transport system and at the same time offers flexibility of data access, security, privacy, decentralized storage, immutability, authentication and the like.

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ANALYSIS OF CYBER SECURITY MECHANISM IN RAILWAY COMPANIES IN ELECTRONIC BUSINESS PROCESSES

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***Abstract** – Railway companies, in accordance with their vision and mission, have the basic task of traffic management as well as the transportation of users and goods. In order to regularly carry out business tasks, railway companies increasingly apply the available systems and technologies of electronic business. Basically, electronic business enables the modern implementation of business activities through digital channels. Today, traditional business models are being completely replaced by innovative digital models based on a large percentage of the use of computer systems in both companies and individuals in their homes. This innovative electronic business system requires the protection and security of all participants in digital communication processes. This paper presents cyber security mechanisms that can be applied by railway companies in business. The main goal is a comparative analysis of the protection mechanism, which includes the components of traditional protection systems that are already in place, up to modern ones that include the application of blockchain technology.*

Keywords - protection mechanisms, cyber security, cryptography, innovative methods of railway e-business.

1. INTRODUCTION

The development of the Internet leads to the application of new technologies in the business of transport companies as well as railways. Railway companies already use the Internet as a network of all networks for the realization of daily business tasks, communication with partners and interested users. The provision of services and the realization of business tasks in e-business enables a large number of operations to be performed faster, more accurately, and more reliably, which involve sending instructions or orders in the form of digital messages. In order for this trend to be on the rise, great attention must be paid to cyber security. Users of the service have the greatest apprehension and aversion to electronic business because they do not have enough information about how secure digital transactions are via the Internet. Employees of the railway company have to learn through various trainings how and in what way to safely participate in the interaction that involves electronic business processes.

At the beginning, the paper includes an analysis of cyber attacks that may occur in the railway company. Redirecting, modifying or fabricating messages in electronic business processes can cause large-scale damage where, in addition to the alienation of financial resources when paying for a certain service, there can also be human casualties. However, this paper will present algorithms and standards that will be replaced by blockchain technology in the near future to increase security in the event of cyber attacks.

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2. THE NEED FOR CYBER SECURITY AND ATTACK MODALITIES

The application of innovative electronic business technologies ensures new ways of exchanging information between interested parties in daily activities [1][2], as well as the application of protection mechanisms. It is basically the application of computers (hardware and software) and the Internet to exchange information in the form of messages. The basic purpose of computer systems is the collection, processing and storage of data, as well as the application of available security mechanisms of all processes in electronic business. In the past, the development of computer systems led to the need for mutual data sharing, which was achieved through networking where there was a possibility of attack. In the world of science, new technical-technological improvements in computer systems are developed every day (e.g. electronic business, 5G and the announcement of 6G networks, artificial intelligence, the Internet of intelligent devices, expert systems, machine learning, etc.). The interested state and private sector, in order to improve daily activities, sees a chance to improve the current operational work through the application of existing and innovative solutions. In essence, the basis is mutual connection and exchange of data and information between interested parties in a protected and safe way [3-6].

In addition to the mentioned usual flow of information, there may be an attack on the availability of the system where there is an interruption in communication (figure 1) [7]. The easiest form of attack can be the interruption of a communication line, damage to a hardware component, obsolescence of a software program, etc.

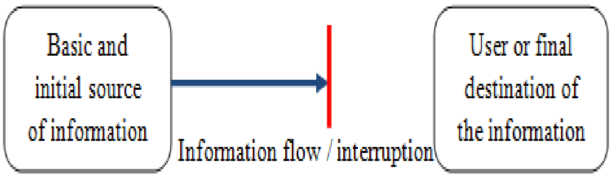

Fig.1. Interruption of the flow of information

Attacks related to integrity (content) involve modifying the message. Then there is a change in the content of the message, which can be a notification, information or even an order. In any case, the recipient of the message does not receive the original message, but a modified one, where the essence of the message and its meaning are changed. The modification of information in the form of a message (e-mail, electronic invoice, electronic bill of lading in traffic, electronic purchase order, etc.) is shown in the figure 2.

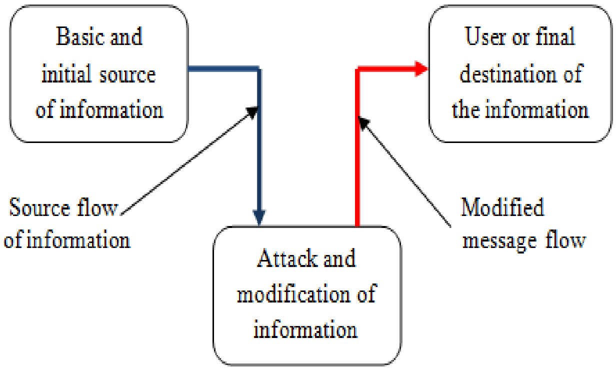

Fig.2. Modified message flow

The next type of attack involves learning about the content of the information being transmitted, its secrecy and confidentiality. In this way, an unauthorized person who does not have the right of access, through interception, gets access to the content of the information. With the help of appropriate software and programs, a third party in the attack can illegally copy the transmitted information. In this case, the searcher or the final destination receives the information without change, but also without knowing that the attacker also received the same information. An example could be the sending of state confidential information, a conceptual solution to a traffic problem, or the discovery of a new medicine in healthcare, etc. Based on the information obtained through interception, an unauthorized person can use it for his own needs. Interception of information is shown in the figure 3.

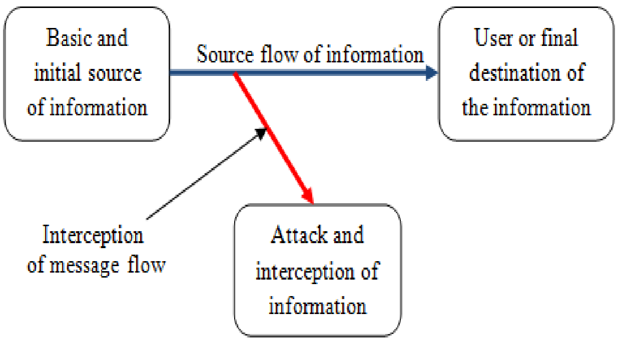

Fig.3. Interception of message flow

The next type of attack refers to information fabrication, where an unauthorized person creates false messages within a possible information stream. An example can be identity theft of a certain person and impersonation by sending messages that have wrong information or modifying some messages in the communication of interested parties. Fabrication of information where the requester or the final destination believes that the message was sent from the correct address is shown in the figure 4.

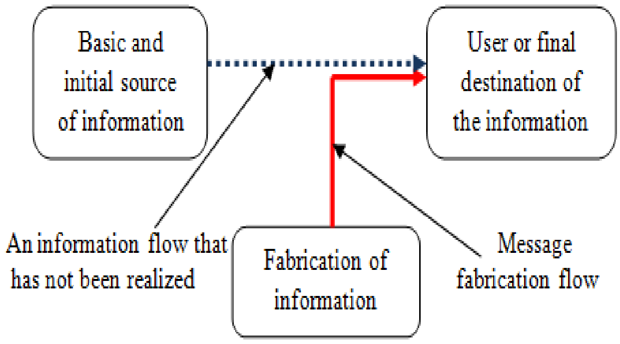

Fig.4. Fabricated message flow

3. PROTECTION MECHANISMS IN ELECTRONIC BUSINESS

Cryptography is the science of secret writing where it has the basic task of securing information from potential attackers. At first, cryptographic techniques allow the sender to mask the data so that if someone tries to intercept it, they don't get any information they can misuse. This implies that the recipient is able to extract the original data sent that has been masked by the sender.

Block encryption means when a message to be encrypted is processed in blocks consisting of bits. For example if the message consists of 64, each one is broken separately and we have blocks of 64 bits. After breaking the message, each block is encrypted independently. When one block is encrypted, a one-to-one mapping is performed and one bit block of the plaintext is mapped into a bit block of the encrypted text. With this mapping, there is a different output for each input. Block encryption allows a large number of mappings and also a large number of combinations that can occur . Each mapping represents one key. If the sender and recipient of the message know a certain mapping, they have the ability to encrypt and decrypt the messages they exchange with each other. For block encryption in this case, there are a large number of combinations. It means that the sender and receiver must have a scheme with as many possible mappings.

Other block cipher algorithms represent standards known by the following names:

- DES (Data Encryption Standard);
- 3DES (3 x Data Encryption Standard) i
- AES (Advanced Encryption Standard).

These operating standards use functions rather than predefined tables as in block ciphers. A string of bits is used as a key in the algorithm. The DES algorithm uses 64-bit blocks with 56-bit keys, while AES uses 128-bit blocks with keys of 128, 192, and 256 bits in length. Table mapping and the number of iterations within the algorithm is the key.

Due to the large number of blocks in the messages that are forwarded and that are too long, a new mechanism has been devised that implies the use of an initial vector for the first block to be encrypted. Chain encryption of blocks is the next protection mechanism and the main characteristics are [7]:

- When encrypting a message, the sender generates a random sequence of bits called the initial vector which is sent as plain text;
- For the first block of encryption, an initial vector is used to calculate the first block of plain text, then the results are passed through the block encryption algorithm and, based on the above, a corresponding block of encrypted text is obtained. The next step involves sending the encrypted block to the recipient;
- The recipient receives a block consisting of an initial vector and an encrypted block of text that is decrypted and can receive the original source text.

4. THE STRONGEST PROTECTION MECHANISM – BLOCKCHAIN TECHNOLOGY

Now the question arises, why is block chain technology the strongest cyber security mechanism in e-business? The answer represents and includes the scalability, security and decentralization of (Figure 5).

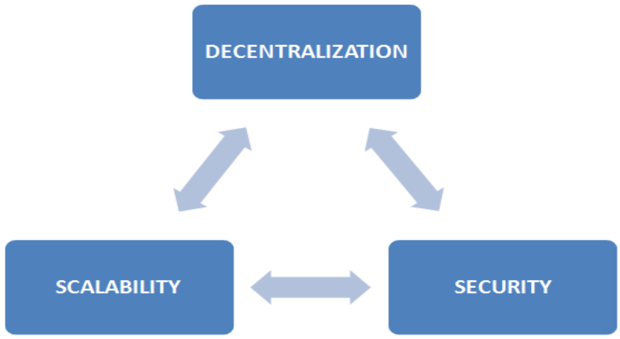

Fig.5. Basic components of blockchain

Decentralization allows remote nodes to manage the network peer-to-peer instead of central control. In addition to the above, decentralization enables each transaction (message exchange) to be validated by more than half of the nodes in the network. There is a possibility of expanding the network where a large number of nodes increases security and at the same time the number of transactions can be reduced. The solution to expanding the network with new nodes is in another basic component called scalability. Scalability has the ability to accommodate a larger number of new applications as well as new transactions without affecting the bandwidth of the entire block chain technology. The network can continuously grow and support new transactions. And finally, security in the block chain network is guaranteed because during a cyber attack, an attacker cannot take over more than half of the nodes that function independently on the basis of decentralization.

For ease of understanding, a six-step process is described below and is presented in figure 6. In the first step, a transaction is initiated by the user or device. The second step is tasked with publishing the transaction to the blockchain network. The following third step executes the consensus using the protocol and at the same time the validation of the initiated transaction is performed. In the fourth step after the transaction is validated, the transaction is grouped with other transactions to form a new block in the main ledger. After that, in the fifth step, a new block is created, which is cryptographically linked to the previous block. In the sixth step, it is confirmed that the transaction that was initiated has been completed.

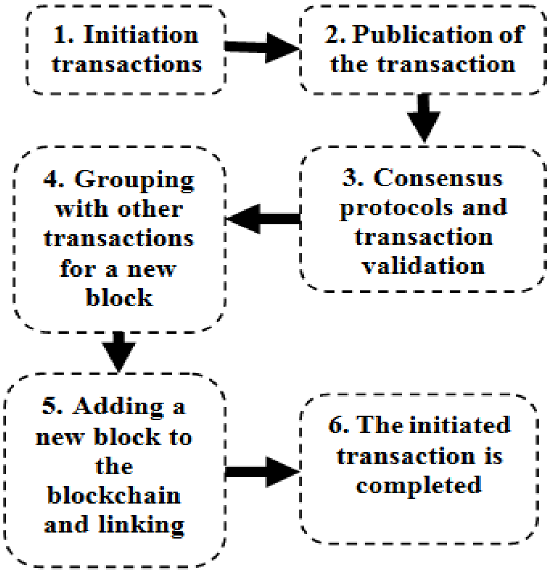

Fig.6. Data protection procedure

5. CONCLUSION

In the recent past, blockchain technology was only applied in the banking sector with cryptocurrencies. Today, the innovative blockchain technology can be applied in all areas of electronic business. A large number of processes in railway traffic and transport take place via computers and the Internet.

In this paper, the available mechanisms for protecting and increasing cyber security in all processes of electronic business are analyzed. Railway companies are increasingly applying technologies and therefore have to secure and insure their personal property as well as the property of partners and potential users. The transparency of the application of technologies should be as accessible as possible and explained in detail to people so that they themselves can introduce the advantages and that their participation in the processes of electronic business is completely safe. Block chain technology as well as its application secures business from cyber attacks in the railway company. The willingness of employees to accept innovative technology can be improved by organizing seminars and teaching so that they can directly communicate the possibility of applying electronic business from their homes in a safe and secure way.

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STOPPAGE OF RSR-OWNED WAGONS IN FREIGHT OPERATIONS

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Abstract *– The stoppage of wagons in freight operations, particularly when the railway operator lacks a sufficient number of wagons in a specific series, adversely impacts the wagon turnaround cycle and freight traffic. This situation can potentially lead to negative consequences in fulfilling transport contracts and increased business costs, necessitating the use of foreign wagons to meet contracted freight transport volumes. This paper analyzes the stoppage of RSR-owned wagons in freight operations during the loading and unloading of various goods. The analysis considers the technology and methods used for loading and unloading, as well as the duration of wagon stoppages on handling and industrial tracks. It proposes improvements to the technological processes of loading and unloading wagons with the aim of reducing wagon stoppages in freight operations.*

Keywords: periods allowed for loading and unloading, type of goods, loading and unloading machinery, handling tracks.

1. INTRODUCTION

Wagon stoppage in freight operations is a key aspect of rail transport efficiency. The process of loading and unloading wagons can significantly affect the productivity, costs and overall operational capability of railway companies. In situations where the wagons are stopped longer than intended, a number of problems arise, including increased costs, reduced availability of the wagons for other transport tasks, and possible delays in the supply chain.

The efficiency of the loading and unloading process directly affects the wagon turnaround cycle, a key indicator in railway traffic. A faster turnaround cycle enables better utilization of the wagon fleet and reduces operating costs.

Conversely, wagon stoppage beyond the prescribed time limits may result in additional fees and penalties (demurrage charges), increasing the total transport costs for customers.

2. PERIODS ALLOWED FOR LOADING AND UNLOADING OF WAGONS AT RSR

Pursuant to the goods tariff RT-131, the periods for loading and unloading wagonloads in freight traffic at the Republika Srpska Railways (RSR) are clearly defined to ensure efficiency and accuracy in the transport process. This regulation specifies different periods depending on the type of consignment and type of train, providing a framework for the planning and execution of logistics operations.

For single wagonloads, the loading and unloading periods are set at 6 hours. These periods allow for quick processing of smaller consignments, reducing wagon stoppage and optimizing the turnaround cycle of the rolling stock. In the case of block trains, which transport larger quantities of goods in the same direction, these periods are extended to 10 hours. This extension is justified by the more complex operations involved in loading and unloading larger quantities of freight.

In regards to the RSR-owned wagons, the periods

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are further specified according to the type of consignment. Single wagonloads have a 6-hour period, while groups of wagons have an extended period of 10 hours. For block trains, the loading and unloading periods are set at 18 hours. These deadlines account for the additional operational and logistical requirements arising from the increased workload and the need for coordination between different parts of the railway system.

It is important to emphasize that these periods are defined irrespective of the loading and unloading technology employed by the customer. This approach ensures uniformity and fairness in applying these periods, providing all customers with equal terms for conducting their logistics operations. Whether utilizing a manual, semi-automatic, or fully automated loading and unloading system, all customers must adhere to the allotted periods to uphold the efficiency and punctuality of rail traffic.

Defining these periods is crucial for enhancing RSR's operational efficiency, minimizing wagon stoppages, and enhancing overall logistical support for customers. Proper management of these periods helps reduce costs and boosts the competitiveness of rail transport compared to other modes

3. OVERVIEW OF RSR KEEPER WAGON STOPPAGE IN FREIGHT OPERATIONS

Throughout 2023, various types of goods were loaded and unloaded into RSR-keeper wagons at stations across the RS Railways network. Iron ore was primarily loaded at Omarska station, coal at Prijedor station, and scrap iron at Doboj and Banja Luka stations, with smaller quantities of other goods. Additionally, tin coils were unloaded at Doboj station, granite stone at Banja Luka station, quartz stone at Vrbanja station, raw sugar at Brčko station, and smaller quantities of other goods were handled at other stations on the RSR railway network.

An overview of wagon stoppage is presented in the Table 1 below.

Tab.1. Overview of wagon stoppage for loading

No.	Loading station/type of goods	Average stoppage period per train/number of wagons	Loading method
1.	Doboj/scrap iron	48 hours/20 wagons	lifter
2.	Omarska/iron ore	2 hours/15 wagons	Specialized facility “Separation”
3.	Prijedor/clay	7 hours/14 wagons	loader
4.	Prijedor/coal	8 hours/16 wagons	loader

The data from the previous table clearly shows that the loading duration varies depending on the facility used. Loading performed by a specialized facility allows for the loading of 15 wagons in approximately 2 hours, averaging 8 minutes per wagon. Conversely, when the consignor loads goods directly from trucks to wagons using a lifter, the process of loading 20 wagons takes 48 hours, averaging 144 minutes per wagon. It is important to note that in this case, the consignor does not store the goods at the loading site but transports them directly by trucks.

An overview of wagons stoppage for unloading is presented in the Table 2 below.

Table 2 indicates that the duration of unloading varies depending on the facilities where the wagons are unloaded. When unloading is conducted using a lifter or by gravity, approximately 12 wagons can be unloaded in about 5 hours, averaging around 25 minutes per wagon. In cases where unloading involves transferring goods from wagons to trucks using a grapple, unloading 15 wagons takes approximately 30 hours, equating to about 120 minutes per wagon.

The preceding analysis demonstrates that the duration of loading and unloading primarily hinges on the technology and machinery available for these operations to the customer.

4. SWOT ANALYSIS

SWOT analysis is a method of marketing research at a strategic level, named after the initial letters of the English words Strengths / Weaknesses / Opportunities / Threats.

Through this analysis, a company can assess its primary advantages (strengths) and disadvantages (weaknesses), as well as identify opportunities (chances) and threats (limitations) that affect its goal achievement [2].

The ultimate objective of the SWOT analysis is to determine the company's strategic position and select

Tab. 2. Overview of wagon stoppage for unloading

No.	Unloading station/type of goods	Average stoppage period per train/number of wagons	Unloading method
1.	Doboj/sheet metal	5 hours/12 wagons	lifter
2.	Banja Luka/granite stone	10 hours/18 wagons	lifter
3.	Vrbanja/quartz stone	30 hours/15 wagons	grapple
4.	Brčko/sugar	8 hours/13 wagons	gravity

Tab. 3. SWOT analysis for RSR JSC Doboj in the domain of transport and relations with transport users

Strengths	**Weaknesses**
• **Standardized periods allowed for loading and unloading**: The defined periods in the goods tariff RT-131 provide clear guidelines and expectations for all participants in the process, enhancing organization and planning. • **Wagon fleet turnround efficiency**: Clear deadlines reduce wagon stoppage times, facilitating faster turnaround cycles and optimizing fleet utilization. • **Improvement of operational processes**: Effective management of wagon stoppages can lead to streamlined operational procedures, minimized downtime, and increased overall efficiency. • **Fairness in implementation of deadlines**: Consistent deadlines irrespective of loading and unloading technologies ensure equitable treatment of all customers.	• **Limited flexibility**: Strict deadlines may pose challenges for users with specific requirements or unforeseen circumstances, potentially resulting in delays and additional costs. • **Technical and organizational problems**: Infrastructure issues, such as faulty loading and unloading devices or manpower shortages, can extend wagon stoppage times. • **Insufficiently integrated systems**: Lack of integration between various IT systems and platforms may hinder the monitoring and management of loading and unloading processes. • **Overdue fees**: Imposition of additional overdue fees and penalties can escalate overall costs for customers.
Opportunities	**Threats**
• **Technological improvements**: Implementation of new technologies, such as automated loading and unloading systems, can reduce stoppage time and increase efficiency. • **Process optimization**: Analyzing data on wagon stoppage may help to identify bottlenecks and improve operational processes. • **Increasing competitiveness**: Improving efficiency and reducing stoppage times can increase the competitiveness of rail transport compared to other modes. • **Collaboration with customers**: Developing partnership relationships with customers and adapting to their needs can lead to better process management and reduced stoppage time.	• **Alternating regulations**: Changes in legislation and regulations can impact operational procedures and increase the complexity of managing wagon stoppages. • **Economic factors**: Economic fluctuations can influence the volume of freight transport, potentially causing resource disparities and increased stoppages. • **Competition with other modes of transport**: Growing competition from road, maritime, and air transport can affect the profitability and sustainability of rail transport. • **Unforeseen situations**: Unexpected events such as natural disasters, strikes, or technical failures can result in significant wagon stoppages and operational disruptions.

an appropriate development strategy.

In this analysis, strengths and weaknesses pertain to internal factors within the company, such as its resources in comparison to competitors and transport service users. Meanwhile, opportunities and threats relate to external factors affecting the transport company.

Advantages denote areas where a company has achieved noticeable success, while disadvantages highlight areas where it has encountered failures [1]. Opportunities are favorable environmental trends, whereas threats are trends that could potentially lead to negative outcomes. Naturally, a company aims to leverage its strengths and opportunities while mitigating its weaknesses and limitations [1].

Given the competition and the relationship between railways and road transport, a specialized analysis is necessary to formulate measures that redirect goods significantly towards rail traffic [1].

To fully capitalize on the advantages of rail transport for users, it is essential to conduct both internal (strengths and weaknesses) and external (opportunities and threats) analyses through a SWOT analysis.

Strengths and weaknesses should be analyzed considering anticipated opportunities and threats. Evaluating competitive advantage underscores the importance of assessing one's position relative to competitors. The initial phase of this analysis involves examining strengths and weaknesses, followed by opportunities and threats (Table 3).

The purpose of the SWOT analysis is to identify internal strengths and weaknesses, along with external opportunities and threats. This analysis enables RSR JSC to assess its capabilities, leverage its strengths, and address weaknesses in response to external changes.

4. CONSCLUSION

The SWOT analysis of wagon stoppage in freight operations underscores the need for ongoing enhancement of technological and organizational aspects to minimize stoppage times and enhance overall efficiency in rail transport. Capitalizing on opportunities for technological advancements and process optimization, while addressing weaknesses and threats, can significantly improve operational outcomes and increase customer satisfaction.

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ANALYSIS OF THE TIMETABLE FROM SREMSKA MITROVICA STATION TO ŠID STATION

Nataša PEJIĆ [1] [0009-0001-0812-1259]

***Abstract** – Transport services are the basic logistical support for human and economic activities. Timetable planning is of primary importance for the transport service quality. In this paper it is presented analysis of the timetable for the trains on the part railway line from Sremska Mitrovica station to Šid station. Analysed technical limitations and possible technological reserves during the exploitation process.*

Keywords – traffic, timetable, trains, railway infrastructure, train composition.

1. INTRODUCTION

Transportation of passengers and transportation of goods represent the basic logistical support of human and economic activities.

Planning and realization of timetable plans, railway traffic as of the dynamic train traffic plan for the transportation of passengers and goods, is the most demanding multidisciplinary process on the railways.

The subject of this work is the analysis of railway traffic, for the purposes of checking compliance with the planned order driving and established technological processes of station operation on the part of the railway network from Sremska Mitrovica station – to Šid station for the timetable 2022/2023. year.

The aim of the papar is to review and analyze traffic functioning according to the set plans, based on the results of the analysis exploitation, that is to identify and investigate possible limiting factors on the infrastructure, as well as technological reserves.

2. TIMETABLE FOR RAILWAY NETWORK FROM SREMSKA MITROVICA STATION TO ŠID STATION IN THE EXPLOITATIONS PROCESSE

Modeling proces and defining problems were performed according to phases as follows:

- Phase 1. Definition of the problem;
- Phase 2. Designing the study;
- Phase 4. Formulating inputs, assumptions, and process definition;
- Phase 5. Data collecting, separating, selecting and preparing;
- Phase 6. Analyzing the results;
- Phase 7. Presenting the results and
- Phase 8. Proposal for measures to improve the train handover process.

2.1. Topology of the railway network from Sremska Mitrovica station to Šid station

On the part of the railway network from Sremska Mitrovica station to Šid station in terms of technical and operational characteristics, there are 4 official places, of which are 2 stops and 2 station. Also, this part of the railway network is 34.7 km a long.

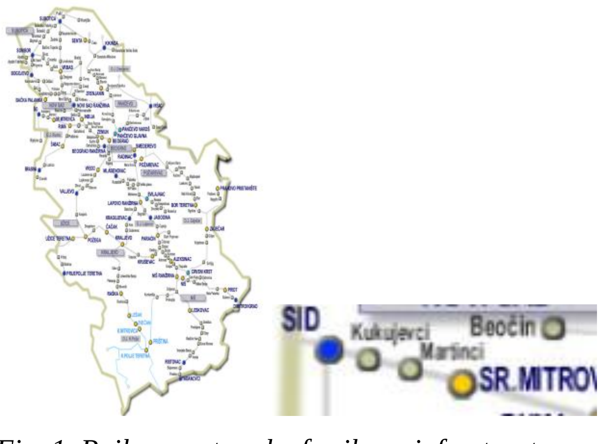

Fig. 1. Railway network of railway infrastructures Serbia - situational view of the railway section from Sremska Mitrovica station to Šid station

Railway network from Sremska Mitrovica station to Šid statio are electrified with the AC traction power supply system of 25 kV and 50Hz. Also, the railway network from Sremska Mitrovica station to Šid station is double-track.

Maximum permitted speed on part of railway network form Sremska Mitrovica station to Šid station we could see in tab 1. From the table it can be seen

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that the maximum permitted speed allowed from Sremska Mitrovica station to Šid station is 30km/h, and for the direction from Šid station to Sremska Mitrovica station to Šid station 100 km/h.

Tab 1. Official places on railway network from Sremska Mitrovica station to Šid station

<table>
<tr><th>Official place</th><th>Maximum permitted speed on the railway for direction from Sremska Mitrovica station to Šid station (km/h)</th><th>Maximum permitted speed on the railway for direction from Šid station to Sremska Mitrovica station (km/h)</th></tr>
<tr><td>Sremska Mitrovica</td><td rowspan="4">30</td><td rowspan="4">100</td></tr>
<tr><td>Martinci</td></tr>
<tr><td>Kukujevci - Erdevik</td></tr>
<tr><td>Šid</td></tr>
</table>

Source: timetable booklet for the timetable 2022/2023. year for railway network 2.1.

2.2. Definition of a problem

The problem under consideration is the ratio of the planned volume of traffic for timetable 2022/2023. year and the existing infrastructure capacities on the part of the railway network from Sremska Mitrovica station to Šid station, in order to investigate limiting factors on the infrastructure, as possible technological reserves. Also, determining the optimal technology for the operation of stations on the part of the railway network from the Sremska Mitrovica station to Šid station for the given timetable and scope of work.

The importance of researching this coherence lies in the fact that, on the part of the railway network for the track from the Sremska Mitrovica station to Šid station, after the reconstruction, there was an increase in the speed of train traffic, but regulation technology of the traffic wasn’t changed. The track for the direction from the Šid station to Sremska Mitrovica station is waiting reconstruction.

Also, in the previous period, there was an increase in the number of railway carriers that lease traces on the part of the railway network from Sremska Mitrovica station to Šid station, which predicted an increase in requests for traffic operations, as well as an increase of shunting work in stations.

2.3. Comparison of the planned timetable with parameters during exploitation

Based on a comparison of the parameters (planned of the elements for the timetable 2022./2023.) that were planned and the parameters obtained during the exploitation process, it was determined that more than 50% of the trains has deviations from the planned elements traffic for the planned timetable. Deviations in the timetable that can be seen in the train traffic logs in more than 70% of cases are due to delays in the handover of trains at the border Šid / Tovarnik. Also, 30% deviations arise as a result of slow customs procedures. Due to the customs procedures in the period of the highest traffic intensity from February to July and in the period from September to December last from 2 to 4 hours per train. Although all freight forwarders prepare and send customs documentation in advance. On the next figure you can see the graph of the planned timetable 2022/2023 for the railway network 2.1. (on next page)

2.4. Proposal for measures to improve the throughput capacity of the Šid railway station

The analysis of the results obtained by the research for the purposes of this work, that the capacities on the part of the railway from the Sremska Mitrovica station to Šid station for the defined traffic organization of the predicted number of trains that regularly operate according to the planned timetable 2022/2023. year and station operation technology satisfactory (there aren't "bottlenecks" on the infrastructure). Proposal of measures to speed up the handover of trains:

- To simplify customs procedures in order to prevent the detention of trains due to customs procedures. Because of that the all trains have accompanying documentation that the forwarders guarantee for the cargo that has been completed by customs procedures
- To apply the handover of trains according to the principle of the traffic schedule, that is, when the trains arrive in Šid station, everyone should prepare for the handover and in an interval when the traffic of the passenger train, allows 4 or 5 locomotives to be received one after the other from Croatia to take over the trains. Of course, if the carriers are interoperable, then just let the train leave the border. in this way, the handover would be done for 4 or 5 trains, instead of just one. If the handover were to be organized in the proposed way, during one 12-hour shift, 12 to 15 trains could be handed over.
- To synchronize the handover of trains so that when the train arrives to Šid, that the locomotive can come in to pick it up.

But, it is necessary to carry out additional research on how to achieve greater efficiency when handing over trains at the Šid/Tovarnik railway crossing.

Because of that long standings trains at the handover, leads to deviations from the planned timetable.

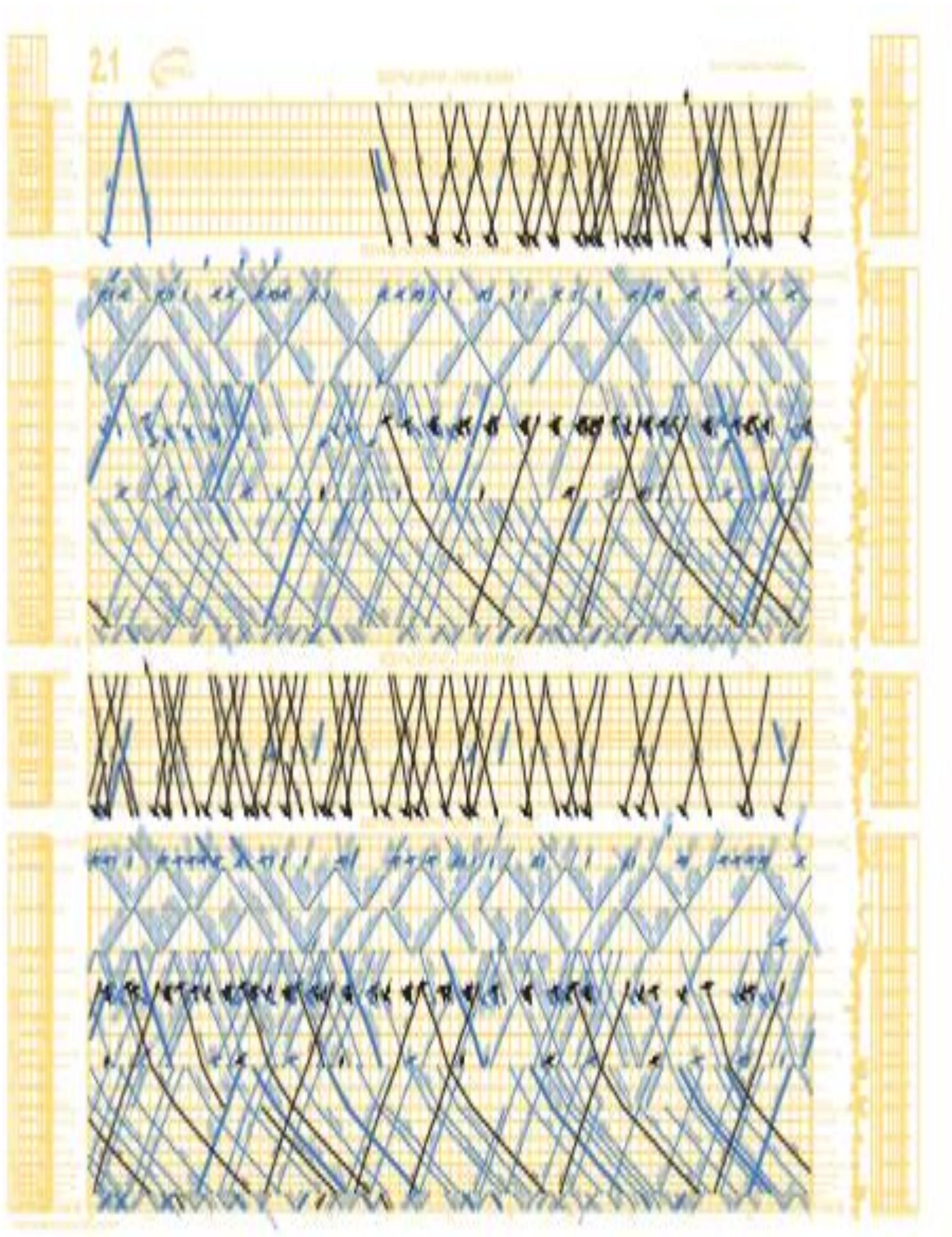

Fig.2. Train graph from 00:00 to 24:00 for the planned timetable 2022/2023 for the railway network 2.1. (Source: timetable 2022/2023. year for railway network 2.1.)

3. CONCLUSION

Due to long standings trains in Šid at the handover, leads to deviations from the planned timetable.The analysis of the results obtained by the research for the purposes of this work, that the capacities on the part of the railway from the Sremska Mitrovica station to Šid station for the defined traffic organization of the predicted number of trains that regularly operate according to the planned timetable 2022/2023. year and station operation technology satisfactory.In order to improve the handover of trains and the realization of the planned elements of the timetable, additional research needs to be done.

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OPTIMIZATION OF SHUNTING PROCESS AT A PASSENGER COMPLEX

Mirena TODOROVA[1] [0000-0002-4138-1861]

Abstract *–The technology of passenger station includes the flow of operations to service the movement of trains and shunting activity to the technical station representing a common railway complex providing the best service to passengers and using the available technical means. The shunting process at a passenger station consists of activities such as handling trains, taking them out of the technical station and their placement on tracks according to the train assembling plan. The paper examines the work of shunter teams and how the number of teams required to serve the passengers railway complex is determined. The study is aimed at possible improvement of shunting process based on a number of selected indicators theoretically worked out: the number and duration of shunting movements per duty; the number and duration of isolated movements; the stay and utilization of shunting teams; the relative occupancy of station tracks. The implementation of the current schedule for the movement of trains and the existing schedule plan for the work at the Sofia station was analyzed and a new one was developed to improve the work of the shunting teams. The developed new scheme of the shunting process ensures reducing the relative employment of shunting teams and the duration of shunting movements.*

Keywords – shunting activity, passenger station, relative occupancy.

1. INTRODUCTION

Passenger railway complexes are built in large cities to serve passenger flows and train traffic. They include passenger stations with facilities for boarding, getting off and serving passengers; technical stations for technical inspection, maintenance, repair and equipment of passenger trains; sheds for stay of carriages and different categories of trains; in some cases there are also locomotive depots and shops for their repair [9]. The mutual location of passenger and technical stations and the specific construction of a throat between them determine the parallelism of train and shunting routes[1, 2]. The full flow of train handling and reduction of reverse train movements on the complex territory to a minimum depends on the layout of passenger railway complex facilities. Rail shunting at stations is an essential process providing continuous receptions and departure of trains, timely pushing to and pulling wagons out of the station, providing minimum time of stay on arrival and departure tracks by effective use of shunting equipment and in compliance with traffic and labour safety. The time required for trains to enter the station before the scheduled departure ensuring comfortable seating of passengers and timely clearing the arrival and departure tracks from trains having completed their run are considered. The improvement and optimization of shunting process is one of the most important tasks in the theory and practice of railway transport organization and management. To provide train traffic, shunting teams perform a significant amount of work and that is used as a basis to determine the necessary number of shunting teams on different shifts.

2. THEORETICAL STATEMENTS

To determine the number of shunting teams required for a given shift, it is necessary to consider the following indicators of shunting work at the station: the number of served passenger trains, the number and duration of isolated movements, the number and duration of shunting operations during the time on duty [5,7,10], the utilization of shunting teams and station tracks [3,6]. In addition, a number of factors have been taken into account: the relatively constant scheme of the shunting process related to the processing of passenger trains and their preparation for subsequent courses, the need for interaction between passenger and technical stations, as well as the location of various passenger train parks.

The duration of movements T_{trav} [min] is determined by the formula:

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$$T_{trav} = \sum_{i=1}^{n}[i * t_{trav,i}] \quad (1)$$

where:
i = 1,2,3…, n – – number of shunting movements;
$t_{trav,i}$ - travel time for the i[th] movement, [minutes].
The duration of isolated movements T_{is_trav} [min];

$$T_{is\_trav} = \sum_{j=1}^{J}[j * t_{is\_trav,j}] \quad (2)$$

where:
j = 1,2,3… J – number of isolated (empty) movements;
$t_{is\_trav,j}$ - travel time for the j[th] movement, [min].

The utilisation of shunting team is reported by the formula:

$$\chi = \frac{T_{work}}{1440 - T_{const}} \quad (3)$$

where:
T_{work} – time of shunting;
T_{const} – time of constant operations;
χ – utilisation of shunting team.

$$T_{work} = T_{trav} + T_{is\_trav} \quad (4)$$

The utilization of shunting team can be reported by the work schedule for each shunting operation. The duration of shunting movements, their number, and the isolated run can be calculated by the schedule of pulling trains out of the station and pushing them to the technical area and then back from it to the passenger station.

To determine the number of shunting teams, it is necessary to consider the total working time of shunting for a shift and depending on the desired time of utilization, to find out the required number.

$$N_{shun} = \frac{T_{work\_sm}}{(1440 - N_{const}) * \chi} \quad (5)$$

The rate of utilisation can be set in the range of 0.75 to 1.00, the latter showing that the shunting team will not have any downtime at disposal. However, this value is not reasonable because a train delay or a carriage breakdown could occur at any time imposing the need of replacement.

The utilisation of station tracks is determined by the expression:

$$\chi_{track} = \frac{\sum(T_{util} + N_{tr}.t_{add})}{(1440 - T_{const\_tr})U_{track}} \quad (6)$$

where:
T_{util} - time when trains are placed on the tracks;
U_{track} - number of tracks;
t_{add} - additional time (accepted to be 10 minutes per train);
N_{tr} - number of arriving and/or departing trains.
T_{const_tr} - time for operations, which are not related to the activities under this study (e.g. passing of a freight train).

In this case the utilisation of arrival and departure tracks is used as a criterion to improve work organization as shunting optimization includes the number and type of shunting movements, which reflects on track utilisation and it increases. The rate of track utilisation is significantly less than the shunting team employment because there are periods with a small number of departing or arriving trains and without trains staying on the tracks. The utilization is usually determined in the morning or afternoon when there is a great number of trains departing from and arriving in the capital of Sofia to serve suburban and long-distance traffic [4,8].

3. CASE STUDY SOFIA PASENGER STATION

Sofia railway station (Sf) is the biggest passenger station in Bulgaria that is connected with the railways of Serbia and Greece, the town of Varna, the suburban line to Bankya and the technical station of Nadezhda through its western station throat and with the railways of Turkey, the freight station of Sofia and the locomotive depot through its eastern throat. All that defines the complexity of station throats, especially in the direction to the technical station of Nadezhda.

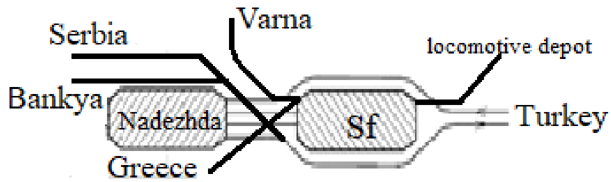

Fig.1. Scheme of Sofia passenger and Nadezhda technical stations

That leads to necessity of parallel routes and simultaneous provision of receptions and departures of trains and shunting operations for pulling trains out of Nadezhda technical station (the distance between the two stations is 1.200 km) as well as replacement of rolling stock (carriages and locomotives) to assemble different trains. The number of served trains is relatively constant and is calculated by Schedule II - 24 for trains that start or end their routes of running at the station. The multiple units (EMU, DMU) move independently to the technical area for external washing, technical inspection and equipment.

The arriving and departing passenger trains that are served at the station of Sofia amount to 115 during the day and 61 for a night shift. The trains pushed to the technical area of Nadezhda are 27 during the day and 14 for a night shift. The Technical Station of Nadezhds is served by station shunters of Sofia Passenger Transport Department at Sofia Station.

The schedules of rail shunting operations are developed before entry into force of the new Train Traffic Schedule and in case of changes in work organization. The rail shunting at Sofia station is carried out by 3 shunting teams during the days and 2 shunting teams on night shifts.

Based on the plan of train receptions and the developed schedules for shunting operations, a Round-the-clock schedule (RCS) is graphically developed once a year before entry into force of the new Train Traffic Schedule. The RCS graphically reflects the sequence and duration of performance of all train handling operations and defines the rules of using technical facilities at the station (Table 1).

Tab. 1. Symbols in the Round-the-clock schedule

Symbol	Meaning
	Track occupation by an arriving train
	Track occupation by a departing train
	Track occupation by a train
	Train handled by shunting team 1
	Train handled by shunting team 2
	Train handled by shunting team 3
	Train pushed to the depot
	Train pulled out of the depot

The developed new organization of shunting activity includes the following changes in Schedule II - 24: use of the 4[th] headshunt in order to relieve the 1[st] and 2[nd] headshunts; increase of shunting operations performed by the team on night shift in the interval 5:30-7:00 instead of pushing to the station in the interval 7:00-8:00; pulling out two trains connected in one to the technical station, which saves one operation and isolated shunting for each similar case; change in pushing to certain tracks so that two trains can be placed on one track but depart in different directions.

Based on the changes made and the types of shunting activities performed by shunting teams, a new organization has been introduced and a new Round-the-clock schedule (RCS) has been developed for daily work (Fig.2) and night shifts.

Table 2 shows the utilisation of shunting teams and arrival and departure tracks at the passenger station, which is used to assess the new organization of shunting work and the previously existing one.

Tab. 2. Round-the-clock schedule – daily work utilisation χ

	Daily old	Daily new	Night old	Night new
Shunting team 1	0,95	0,89	0,96	0,90
Shunting team 2	0,96	0,84	0,95	0,89
Shunting team 3	0,95	0,83		
Tracks	0,56	0,57	0,57	0,59

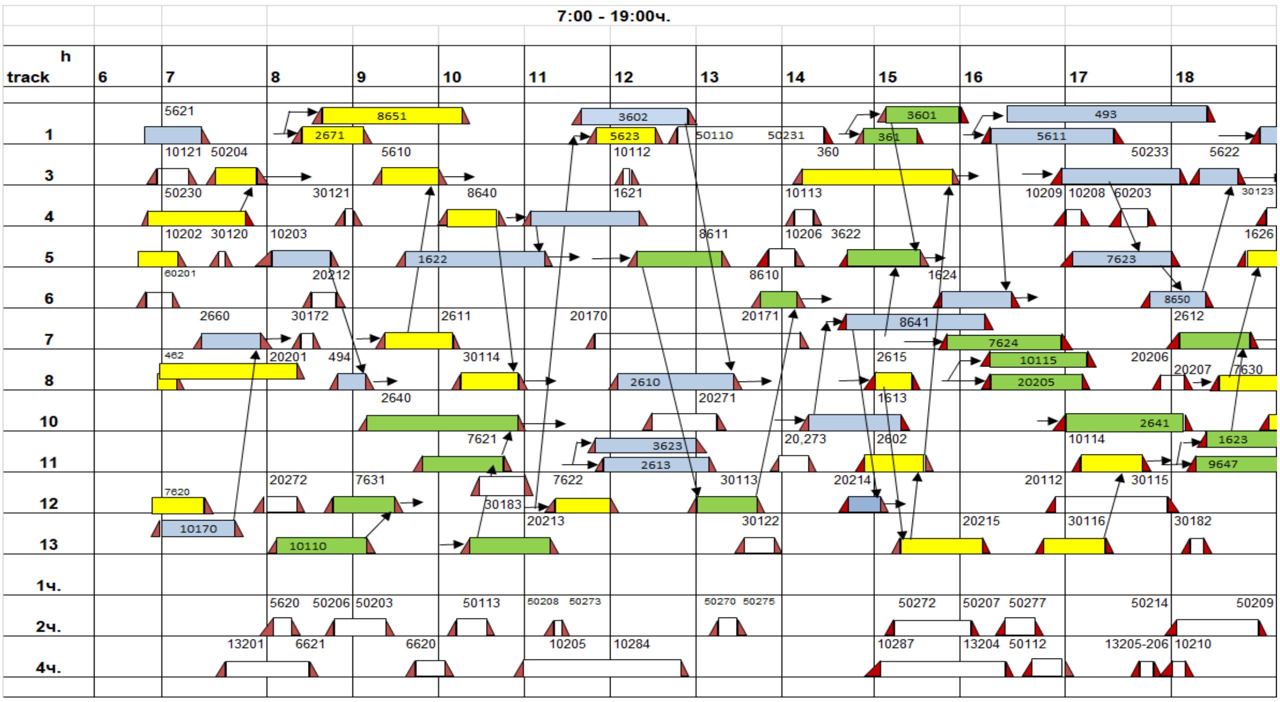

Fig.2. Round-the-clock schedule

4. CONCLUSION

The purpose of developed new organization is to optimize the activities of shunting teams by reducing their workload. In recent years the number of passengers using railway transport has decreased and, accordingly, the number of carriages in a train has also been decreased. That makes possible to push two trains from the technical station to the passenger station and in reverse using one shunting operation for the trains ending their travelling at the passenger station.

In the examined specific case Shunting team 3 works only during the day, but depending on the planned activities, shuntimg teams might work 8 hours or serve several neighboring stations. With the change in Schedule II - 24, the utilisation of tracks is also taken into account and used as a criterion to make assessment of the implemented optimization. The change could be estimated as successful if the track utilisation is not increased by more than 0.05. The theoretical formulation presented in this paper can be applied not only to passenger stations, but also to stations with intensive shunting activities.

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POSSIBILITY OF APPLYING MODERN SYSTEMS FOR THE SALE OF TRANSPORT SERVICES IN RAILWAY PASSENGER TRAFFIC AT RSR

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Abstract *– The advantages of employing modern systems for selling transportation services in railway passenger traffic are manifold, benefiting both users and the carrier, in this case, the railway company. However, transitioning to modern systems in the organization of passenger transport within Republika Srpska Railways faces challenges, including the need to address existing restrictions which would require significant material and resource investments. Presently, ticket sales at RS Railways primarily rely on traditional methods such as K-6 surcharge blank-to-blank tickets and leaflet tickets. However, these methods present numerous drawbacks, including unclear basic data entry, incomplete information, and potential misuse. Moreover, processing issued surcharge blank-to-blank tickets involves challenges such as tariff control, revenue allocation in domestic joint traffic, and data submission on total revenue and dispatched passengers. To meet the increasingly diverse demands of transport users and improve operational efficiency, one viable option is the implementation of electronic ticketing devices onboard trains. Experiences from foreign railway administrations that have adopted mobile terminals indicate improvements in service quality, ticket inspector productivity, and revenue management, along with enhanced accuracy and reliability in income determination and reduced potential for manipulation. These advancements facilitate more effective planning and organization of passenger transport processes.*

Keywords – system for the sale of transport services, passenger transport organization, onboard ticket sales.

1. INTRODUCTION

Most railways organize the issuing of railway tickets in passenger traffic by developing three sales networks:

- at railway stations,
- in trains,
- in travel agencies.

The sales network in railway stations includes ticket offices in the stations themselves. Spatial proximity of sales points to the starting point of the trip is, on the one hand, an advantage, but on the other hand, overestimating the importance of this factor had a negative effect on the development of the commercial function in passenger traffic because other marketing activities were neglected.

The sales network in the trains is based on the activities of the attendant conductors. The basic task of this sales network is the collection of fares for passengers without travel tickets, or with inadequate travel tickets, and the collection of special catering services.

The sale of railway tickets in travel agencies is one of the measures that should have provided the greatest contribution to the consolidation of the railway's market position. Travel agencies could sell railway tickets in domestic and international traffic and commercialize the railway's offers, on the basis of which they would be entitled to a part of the collected transport revenue.

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The main reasons for connecting companies to the Internet are a direct connection with millions of computer users in the world and the transfer of information that reaches users in the shortest possible time. By connecting to the Internet, you can efficiently offer content, communicate with other business entities, and thus increase business productivity.

2. POSSIBILITY OF APPLYING MODERN SYSTEMS FOR THE SALE OF TRANSPORT SERVICES AT THE RAILWAYS OF REPUBLIKA SRPSKA

The transport system is one of the main pillars of the development of the modern economy, while railway transport is an integral part of this system. The development of railway traffic implies the rational use of existing resources, efficient management and organization, standardization, as well as the application of modern technologies while respecting environmental requirements. It can be concluded that the Railways of Republika Srpska (hereinafter: RS Railways) should introduce new technologies so that they do not fall behind technically and technologically compared to other transport branches and to enable greater participation in the market of transport services [1].

At the moment, RS Railways on its internet portal enables the electronic calculation of ticket prices in internal and inter-entity traffic.

However, building an Internet network on the RS Railways would enable better organization and availability of information to service users, such as: timetable, tracking of freight cars and goods, sale of tickets in international rail traffic, reservation of seats, payment transactions, monitoring of investments, personnel information system and others.

This network requires investment in the form of adequate electronic equipment, computer networking, provision of a larger number of servers, hiring of experts for the maintenance of the hardware and software system, as well as training of staff for its use.

One of the possible applications of the Internet in the RS Railways is reflected in the possibility of connecting the aforementioned network with the computer networks of neighboring railway administrations, in order to achieve a faster exchange of data on the movement of goods and passengers.

A computer network organized in this way would provide the possibility of connecting with other railway administrations in Europe, so that international data exchange for some joint projects would be enabled.

In order to buy a train ticket online, the service user would have to have a computer or mobile phone with internet access, an e-mail address and a valid Visa or MasterCard payment card [2].

After successfully paying for the transport service via the Internet, the user should receive an e-mail that would be a confirmation of the completed payment of the train ticket. This confirmation, which would contain basic information about the trip and the payment made, would be printed by the service user, on white A4 format paper. Based on the printed confirmation, the passenger would pick up the train ticket at the passenger ticket office of the train departure station or from the conductor.

In order to meet the increasingly diverse demands of transport users, as well as the desire for more efficient operations, one of the possibilities would be the introduction of a device for the electronic issuance of transport tickets on the train.

The sale of train tickets on the RS Railways is mainly limited to the issuance of K-6 surcharge tickets, as well as printed train tickets. The disadvantages are numerous, both in the field of issuance (unclear entry of basic data, incomplete data, abuses), and in the processing of issued surcharge tickets (tariff control, distribution of revenue in internal shared traffic, submission of data on total revenue and number of dispatched passengers).

The experiences of foreign railway administrations in the introduction of mobile terminals indicate that there has been an increase in the quality of the transport service, the productivity of the conductor's work on the train, an easier, more accurate and more reliable way of determining the income from tickets sold on the train, as well as a reduction in the possibility of manipulation. This ensures more successful planning and organization of work in the process of transporting passengers by rail [2].

The system for issuing electronic tickets on the train consists of two basic subsystems:

- Hardware:
  - ✓ mobile terminal whose main parts are: alphanumeric keyboard, display, printer, data storage medium, power supply device, other communication parts,
  - ✓ device for reading data and "transferring" it to the PC,
  - ✓ device for connecting to a PC,
  - ✓ battery charging device and
  - ✓ PC configuration.
- Software:
  - ✓ system software that enables the operation of mobile terminals,
  - ✓ application software (program for electronic ticket issuance),
  - ✓ software for reading data and processing it on a PC.

Given that mobile terminals achieve complete accuracy when calculating the price of a train ticket, increase the speed of issuing tickets, eliminate misuse, achieve a reduction in the cost of forms, bills and facilitate data processing, the need to introduce these devices is obvious. What could be an obstacle in the realization of this idea is the high price of the equipment, as well as the incompatibility of our trains with electronic devices such as mobile terminals.

Another additional service that the railway can provide to the users of its services is the purchase of a train ticket using a mobile phone. Passengers will be able to purchase a train ticket with the help of a smartphone.

Passengers who wish to use this service should first register on the internet portal, in order to receive a personal identification number (PIN). To buy a ticket, it is needed to send an SMS message with a phone number and PIN number, and tickets can be paid for by credit card [3].

The last deadline by which passengers can buy a ticket with the help of a mobile phone is 10 minutes before the train departure, and after the purchase, the passenger receives an MMS message with a bar code that, with the help of a special reader, is read by the conductors on the train.

In order to improve the transaction of buying train tickets on the RS Railways, it is necessary to develop a system using Metcard train tickets. One ticket enables flexible travel, simply buy the ticket, validate it and travel.

Metcard tickets could be purchased:

- at all main stations,
- in shops with blue Metcard signs,
- by calling the corresponding number,
- at the corresponding internet address [3].

The Metcard must be validated because driving without a validated card can result in a fine.

The types of Metcard train tickets are:

- 2-hour Metcard train tickets allow an unlimited number of train journeys, during at least 2 hours, within the zones covered by the ticket. 2-hour Metcard tickets validated after 6:00 p.m. are valid until 2:00 a.m.
- Daily Metcard train tickets allow an unlimited number of train journeys, throughout the day, within the zones covered by the ticket.
- 10 x 2-hour Metcard train tickets provide ten 2-hour journeys at a lower price, but can only be used by one person.
- The 5-Day Ticket Pack includes five daily Metcard train tickets in one booklet, available at a discounted price.
- The 5 x daily Metcard ticket covers five daily tickets in one Metcard train ticket. They are available at the main stations, and can only be used by one person.
- The weekly Metcard allows an unlimited number of journeys during a seven-day period, within the zones it covers. A weekly Metcard can be used for weekend travel within zones regardless of which zones the ticket covers.
- A monthly or annual Metcard allows an unlimited number of train journeys within the zones it covers, for a month or a year. A monthly or annual Metcard can be used for weekend travel within zones regardless of which zones the card covers.
- Group Traveller Metcard card allows two adults and up to six children to travel in zones at a reduced price. Children must be under 15.
- A pre-paid ticket for group travel and excursions allows groups of 12 or more people to travel together by train, with a discount [3].

3. SWOT ANALYSIS OF POSSIBILITIES AND LIMITATIONS FOR THE APPLICATION OF MODERN SYSTEMS FOR THE SALE OF TRANSPORT SERVICES AT RS RAILWAYS

A large number of indirect and direct factors that influence the formation of conclusions about the consequences that the introduction of new technologies has on the development of railway companies, but also on society in general, as well as their character, imposed SWOT analysis as a possible methodology for recognizing these results. Its focus on potentials and limitations is precisely what is primary for determining development guidelines at this level.

S (Strenghts):

- raising the level of service quality,
- simpler access to railway system services by users,
- more rational and efficient service billing process,
- achieving faster passenger flow and greater travel comfort,
- increase in turnover and capacity utilization,
- simpler introduction of new tariff systems,
- reducing the human error factor,
- improvement of the general image and market position of the carrier.

W (Weaknesses):

- high cost of introducing the system,
- the need for specialized professional staff,
- great interdependence of individual elements of the system,
- the necessary existence of developed and branched internet technology,
- impossibility of partial activation.

O (Opportunities):

- increase in revenue from the sale of train tickets,
- renewing the infrastructure and increasing the speed of transport,
- restructuring of business processes in the

company,
- separation of income by individual destinations.
- reducing the cost of issuing tickets,
- disposal of a larger amount of information about traffic flows,
- proper distribution of realized income and more reliable development planning,
- possibility of integration with other billing systems.
- better information about services**,**
- cashless payment for transport services,
- easier purchase of tickets,
- a greater selection of ticket options (the passenger is able, depending on his needs, to choose a time ticket or a ticket with stored value),
- economy (time tickets are not tied to the date but to the start of their use, so there is no unused tickets),
- the right to a discount for privileged categories of passengers,
- passenger loyalty program, award bonuses based on the number of trips,
- better adaptation to the touristic segments of the environment by combining the transport service with tourist arrangements.

T (Threats):
- the formation of a disjointed system whose control is difficult,
- the high price of the intervention, the effectiveness of which is proven in practice only after the activation of the entire system.
- price non-competitiveness in relation to other modes of passenger transport in the system introduction phase,
- possible errors in the system implementation phase,
- failure to accept new technologies.

4. CONCLUSION

Already today, it is difficult to imagine life without the Internet, both for individuals and for any company, and what impact global computer connectivity will have on life in all its forms "tomorrow", is a topic that interests a good part of humanity.

Many people, potential users, have been using the computer for a long time and they are increasingly dependent on its services. This dependence has increased tremendously with the inclusion of users in one of the existing computer networks.

Today, there is almost no service that is not available online. The advantages brought by internet technology, which are important for the railway business, are primarily reflected in the possibility of increasing the reputation of the railway, increasing the number of passengers, expanding the form of cooperation between individual railway administrations, faster and better communications.

The possibilities of reserving a suitable place (seats, beds) and choosing a transport route using the Internet are especially relevant. By presenting the range of offers in passenger rail traffic, the services of railway companies become available to all potential users of its services.

The effects that can be expected from the inclusion of RS Railways in the global computer network are:
- increase in sales of products or services,
- increasing the company's reputation, both domestically and internationally,
- the possibility of offering current information, which is not feasible with traditional media without increased costs,
- the possibility of systematic market research and monitoring of user behavior depending on the measures implemented by the railway company (through e-mail, mailing lists, discussion groups, and FAQ),
- enabling service users to learn about available potentials, as well as planned services,
- expanding interactivity, i.e. all forms of communication with passengers (explanations, surveys, questionnaires),
- attracting the necessary personnel to work on the railway,
- reducing costs, because the Internet is the cheapest medium of communication.

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LIFECYCLE COST CONSIDERATIONS OF COMPUTER BASED LEVEL CROSSING PROTECTION SYSTEMS

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Abstract *– This paper deals with the lifetime cost of various computer-based level crossing (CBL-xing) protection system. During the several decades of application CBL-xings protection systems have been following and unseeing the technological advances related to the electronic and computer based hardware. As a result, they use different hardware with various generation of processors and consequently, have various reliability characteristics. All CBL-xing systems have to have very high safety integrity level (SIL) in accordance with CENELEC standards. Usually SIL4 is required. Mostly they have two times two (fail-safe) architecture of the central control computer and a high degree of modularity to allow for the scalability and ability to equip all range of various applications. During the evolution of CBL-xing systems their control modules have experienced higher degree of integration and hence, contributed to minimise design, installation and testing time. Also, the technology advances are used for the realization of all CBL-xings modules, hence contributing to their increased reliability. The MTBF values of the modules of nowadays CBL-xing systems are significantly higher if compared with the MTBF values of some other systems that are realised in earlier time. Although all CBL-xings are mostly comparable from the safety point of view, they may significantly differ from the reliability point of view. The safety characteristics of a CBL-xing are usually required, considered and evaluated at the purchase time, but reliability requirements are often omitted. This approach can cause significant hidden costs during the long lifetime of a CBL-xing. The purpose of this paper is to show how much a CBL-xing system really cost during its lifetime and to demonstrate advantages of high reliable and low power consumption CBL-xings. Savings related to amount of spare parts, maintenance expenses and traffic delays, as well as electricity consumption costs during the 20 years of lifetime of a CBL-xing, are considered and highlighted.*

Keywords - computer-based level crossings, reliability, maintenance, traffic delays, electricity consumption cost, lifecycle cost.

1. INTRODUCTION

The latest CENELEC standards for railway applications have introduced the concept of the life cycle of a CBL-xing protection system [4]. The life of a CBL-xing system after commissioning is regarded from an exploitative point of view. Hence, beside the safety, a significant amount of attention is given to the reliability, availability and maintainability that are of paramount importance for the users. This simply recognises the weight that the *Railway Authorities* - RA put on maintenance issues nowadays.

Tendering processes for signalling products in general, including CBL-xings, for the selection of successful tenderers in the past, only had the technical compliance with the technical requirements and the price. The price has mostly covered the complete realisation of a CBL-xing, as a onetime cost. The cost for a certain quantity of spare parts was also considered by a tender in some cases. But, the complete maintenance cost during its life (usually 20 years) has not been considered in any tender's requirements nor as an award criteria. The reliability and consequently the availability of a CBL-xing system practically determine the lifetime maintenance expenses and have a significant impact on traffic disturbance and traffic delays. The maintenance expenses, disregarding the cost of spare parts, include expenses of the maintenance personnel involved. Potential losses due to traffic delays caused by the failed equipment during the lifespan have also not been considered as one of the winning criteria in any tendering process.

The purpose of this paper is to highlight the significance and value of the total exploitation

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expenses of a CBL-xing protection system. Maintenance expenses and traffic delay losses, during the lifetime of a CBL-xing, will be considered in order to show the advantages of CBL-xing systems with higher reliability and higher availability. The practical example of the relevant expenses will be given using simplified calculations applied to various versions of CBL-xing systems, classified by different reliability features. The comparison between different CBL-xing systems, in the aforementioned context, will be shown below and the advantages of the CBL-xing systems with a higher reliability will be highlighted.

2. TYPICAL CBL-XING APPLICATION

The typical track layout of a CBL-xing system for for a single track application is shown in Figure 1.

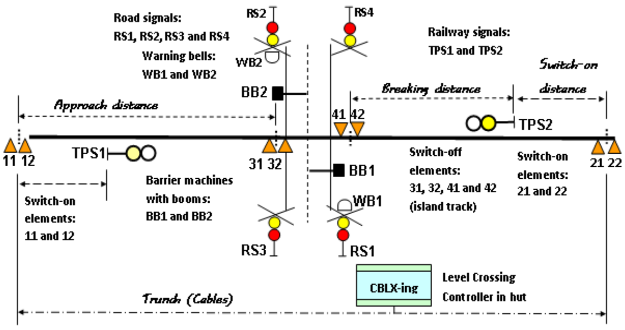

Fig.1. Typical track layout of a CBL-xing system

CBL-xing contains inside and outside equipment. Inside equipment is realised in the controlling cabinet, which is placed at the hut near the crossing. It contains a power supply and the level crossing controller. The controller is responsible for the safety of the system. Therefore, its CPU is realised as a 2 out of 2 (2oo2) system (duplicated for safety).

Road related outside equipment is practically independent of the number of tracks and consists of: boom barriers with booms (BB1 and BB2), road protection signals (RS1, RS2, RS3 and RS4) and warning bells (WB1 and WB2). Road signals are realised as a road traffic lights (semaphores) with LED light modules.

Railway related outside equipment is track and traffic direction dependent and for one bi-directional track usually consists of: train protection signals (TPS1 and TPS2), two pairs of switch-on elements (11/12 and 21/22) and two pairs of switch-off elements (31/32 and 41/42). Power supply usually contains two identical parts (PS1 and PS2). Switch-on (11/12, 21/22) and switch-off (31/32 and 41/42) elements are duplicated for the availability. Also, the road signals (RS1/RS3, RS2/RS4) are duplicated for the availability. In addition, road signals use LED light modules instead of classical signal bulbs to significantly increase reliability. MTBF of road signal LED modules is over 5 years, instead of 600h for the bulbs. Similar situation is with the train protection signals (TPS1 and TPS2), which also use rail LED lights modules with the life expectancy over 10 years.

All modules are of a CBL-xing system are removable, plug in modules, that enable easier and faster replacement (first line maintenance) and significantly reduces MTTR on sight, contributing to the higher availability of the entire system.

3. RAMS FEATURES OF CBL-XINGS

A CBL-xing is a scalable system. It can be used for various track layouts. The size and capacity of a CBL-xing will mostly depend on the number of railway tracks over the road and a place of the crossing (open line or railway station area). Typical application, presented on Figure 1, will be used to show the principle of the MTBF calculation and availability considerations for a CBL-xing system and to highlight the influence of reliability of particular subsystem and parts to the reliability of the entire system. Reliability of a CBL-xing system, for the same application, is mainly dependent on the technology used and producer's concept related to the number and quality (reliability) of the containing parts of the system.

Central 2oo2 computer with its digital inputs and outputs - DIOs is usually highly reliable. It is expected that this part of the system has the same life expectancy as required for the entire system (usually 20 years). As a result, the most producers do not use redundancy for the availability for the CPU 2oo2 computer and its DIOs.

Parts of a CBL-xing that have lower reliability are duplicated for availability, and a failure in one of their channels will not affect the availability of the system as a whole. Although their duplication contributes to a decrease in reliability of the system, the advantages related to availability have prevailing. As the maintenance repair time in very short (for example, 4h) the probability of having a second failure of the remaining redundant element leading to the interruption of the work is very small.

As a result, from the availability point of view, the most critical parts are the parts realised as a single elements with the lowest reliability.

4. TYPICAL CBL-XING ARCHITECTURE

For the calculation of the practical reliability and availability values of a CBL-xing system, we will use an example of a CBL-xing for typical application from Fig.1. The simplified architecture of a CBL-xing system, for typical application from Fig.1, is shown in Figure 2, with MTBF data of the most relevant parts.

The MTBF values for batteries (maintenance free), road signal LED modules, rail signal LED modules, boom barriers with booms and LPM – lighting protection modules are close to the realistic as given by their producers and rounded for easier calculation. The average values of MTBF of all other electronic equipment are also rounded (MTBF=: 250.000h / 500.000h / 1.000.000h / 1,500.000h / 2.000.000h) in relation to the technology used at the time of realisation (marked respectively as Type: A /B / C / D / HR) in order to make the calculation easier and to demonstrate a general approach.

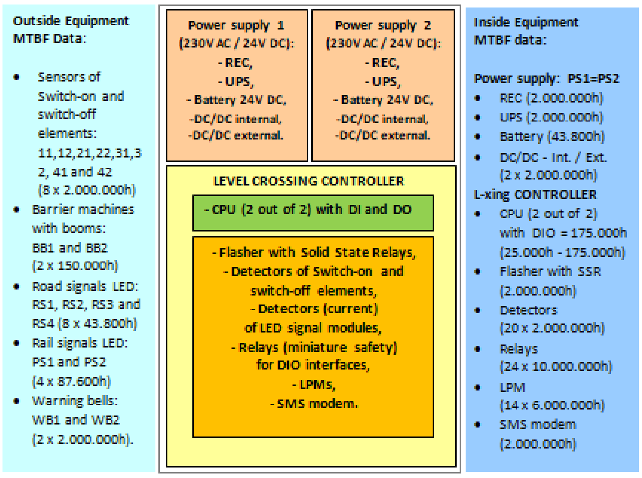

Fig.2. CBL-xing architecture with MTBF data

5. CBL-XING RAMS CALCULATION

Earlier developed processor boards based on 16-bit processors have, in general, the MTBF of about 50.000h (marked as Type A). Type B is related to next generation 80286 CPU boards (MTBF=100.000h). Type C covers 80386 CPU boards (MTBF=150.000h). Type D represents recent CBL-xings (due to the very long implementation time of new computer base technology into the safety related signalling products) based on 80486 CPUs and more advanced processors and architectures including RISC processors for safety applications (MTBF=200.000h) [3].

During the last decade we have experienced new *Commercial-off-the-shelf* - **COTS** controllers, which are used for the realisation of *High Reliable CBL-xings* - **HR CBL-xings**. COTS controllers are comprised of standard components and can therefore be produced, sold, and operated at significantly lower cost. They have a very high reliability (For Type HR MTBF is about 350.000h) and they are approved as SIL 4 for railway application in accordance with CENELEC standards [2].

CPU 2oo2 and DIOs are comparable from the MTBF point of view (usually realised as two units). Hence, we will assume that all DIOs have the same MTBF as CPU 2oo2 and complete CPU (2 out of 2) with DIOs will have a half of MTBF of CPU 2oo2.

In accordance with previous considerations the reliability of the complete CBL-xing system can be expressed via MTBF of its parts. Here, we will use the MTBF data, which are related to the all parts of the CBL-xing of Type HR, as shown in Figure 1.

Number of failures - Failure rate and MTBF of the power supply are:

λ(PS)= λ(PS1)+λ(PS2)=2*λ(PS1)=2*[λ(REC)+ +λ(UPS)+λ(Bat.)+2*λ(DC/DC)]=**4.97E-05/h**.

MTBF(PS)=1/ λ(PS)=**20.136h.**

Failure rates and MTBF of the CPU 2oo2+DIO are:

λ(CPU+DIO)=5,71E-06/h.

MTBF(CPU+DIO)=1/λ(CPU+DIO)=**175.000h**.

Failure rates and MTBF of the remaining L-xing controller parts are:

λ(L-xing CP)=λ(Flesher)+λ(Detectors)+ +λ(Relays)+λ(Modem)=**1,57E-05/h**.

MTBF(L-xing CP)=1/λ(L-xing CP)=**63.559h**.

Failure rates and MTBF of the complete L-xing controller are:

λ(LXC)=λ(CPU+DIO)+λ(L-xing CP)=2,14E-05/h.

MTBF(LXC)=1/λ(LXC)=**46.625h.**

As a result failure rate and MTBF of the Inside Equipment are:

λ(IE)= λ(PS) + λ(LXC) = 7,11E-05/h.

MTBF(IE) = 1/λ(IE) = **14.063h**.

Failure rate and MTBF of the Outside Equipment are:

λ(OE)=λ(Switches)+λ(BBs)+λ(RS)+λ(TPS)+ +λ(WB)=2.47E-04/h.

MTBF(OE)=1/λ(OE)=**4.054h.**

Finally, failure rate and MTBF of the CBL-xing are:

λ(CBL-xing) = λ(IE) + λ(OE) = 3,18E-04/h.

MTBF(CBL-xing) = 1/λ(CBL-xing) **= 3.147h**.

In accordance with the above example, it is possible to calculate simplified or precise MTBF of a CBL-xings for various applications depending on the availability of the accurate MTBF data for all parts.

6. RAMS DIFERENCES OF CBL-XINGS

During the course of 40 years of being applied, various CBL-xing systems have been developed [1]. During the last several years, some RA have been requesting the submission of MTBF data within the tenders. The RAMS numerical characteristics of a CBL-xing are mandatory by CANELEC standards in the aim to demonstrate an appropriate safety integrity level. Hence, the RA will be able to compare the MTBF data of various CBL-xing systems during the tendering phase. The following analyses can serve as an example of determining which CBL-xing system will prove to be the cheapest during its lifespan.

In the aim to compare CBL-xing systems we would have to compare their architecture and determine the MTBF values of their parts that are generally not publicly known. But, the MTBF of the processor boards (CPUs) can be approximately determined based on the level of technology and type of processors used [2]. It is reasonable to assume that the DIOs and the other electronic parts of the system also follow MTBF rates of the CPU technology at the time of system development. Hence, the MTBF characteristics of a CBL-xing system can be determined by analogy to the here presented calculation example for a CBL-xing. In accordance with the above mentioned considerations, various generations of CBL-xing systems and their MTBF values are compared and shown in Table 1. Table 2 presents the number of failures, i.e. required quantity of spare parts, for the analyzed CBL-xing systems, for the lifetime of 20 years.

Tab.1. MTBF of CBL-xing systems and its parts

TYPE	CBLXing Total	CPU + DIO	Controller Parts	Controller Total	Power Supply	Outside Equipm.
	MTBF [h]	MTBF [h]	MTBF [h]	MTBF [h]	MTBF [h]	MTBF [h]
A	2,032	25,000	10,784	7,534	12,876	3,551
B	2,551	50,000	20,520	14,549	16,217	3,822
C	2,895	75,000	37,406	24,958	18,635	3,974
D	3,042	100,000	51,546	34,014	19,610	4,027
HR	3,147	175,000	63,559	46,625	20,136	4,054

From the presented results we can conclude that influence of the reliability of the outside equipment and power supply is practically the most important. Also, the reliability of the remaining controller parts under the control of CPU makes more influence to the MTBF of CBL-xings then the safety CPUs with DIOs.

Tab.2. Number of failures of the CBL-xing systems

TYPE	CBLXing Total	CPU + DIO	Controller Parts	Controller Total	Power Supply	Outside Equipm.
	Failures	Failures	Failures	Failures	Failures	Failures
A	86.21	7.01	16.25	23.25	13.61	49.34
B	68.69	3.50	8.54	12.04	10.80	45.84
C	60.51	2.34	4.68	7.02	9.40	44.09
D	57.59	1.75	3.40	5.15	8.93	43.50
HR	55.67	1.00	2.76	3.76	8.70	43.21

With the goal of estimating the value of the spare parts and maintenance repair time (MTTR of 4h), we can assume that the electronic modules of all analyzed systems have the same price of EUR 3.500, except the CPU and DIOs that have the same price of EUR 35.000 and a maintenance hour price of EUR 250.

The duration of traffic delays, during the lifetime is proportional to the number of faults and MTTR. Failures of the parts have different influences on the availability of the system. The most critical are non-redundant parts with the low MTBF rate (like batteries and road signal LED modules). The accurate analyzes of the elements, which are critical in terms of traffic disruption, depend on the topology of a L-xing and the operational constrains. Therefore, for the further analyses we can assume that only 25% of failed parts will create traffic delays. We can also assume that the duration of a traffic delay will be ½ of the maintenance time required to clear a fault of the part that is responsible for the traffic delay. This way, the total traffic delay time will be 12,5% of the total maintenance time for the lifetime of an L-xing. Losses related to the traffic delays are dependent on the importance of the line. Traffic delay hours are differently rated for various RA (countries). For calculation purposes we will assume that the losses are around EUR 15.000 per 1h of traffic delays. Then, the total lifetime expenses (in EUR) for the analyzed CBL-xing systems, including spare parts, maintenance time and traffic delays, are presented in Table 3.

Total power consumption of CBL-xings varies (from 250W to 1.500W), influencing their lifetime expenses. Lower electricity consumption cost should also be an advantage in the evaluation of tenders.

Tab.3. The lifetime expenses of CBL-xing sysstems.

TYPE	CBLXing Total	CPU + DIO	Controller Parts	Controller Total	Power Supply	Outside Equipm.	MTTF 4h / failure	TD 0,5h / failure
	EUR	EUR	EUR	EUR	EUR	EUR	EUR	EUR
A	1,255,215	245,280	56,864	302,144	47,622	172,704	86,205	646,540
B	934,599	122,640	29,883	152,523	37,811	160,440	68,685	515,140
C	799,695	81,760	16,393	98,153	32,906	154,308	60,509	453,820
D	746,259	61,320	11,896	73,216	31,270	152,264	57,589	431,920
HR	699,541	35,000	9,648	44,648	30,453	151,242	55,670	417,528

7. CONCLUSIONS

The total initial investment cost for a CBL-xing in the past can be estimates in range of EUR 350.000. It is visible that the lifetime cost of the older generations of CBL-xings is few times higher. Also, the lifetime cost represents a significant amount in comparison to the initial investment cost. The consideration above justifies a need to include the reliability characteristics of a CBL-xing system in the tenders in order to select the best bidder.

The analyses presented in this paper can be used as a guide to determine the real expenses of an L-xing system during its lifetime. The RA can conduct more accurate analyses with the real parameters. As a result, they will be able to select the most economical system for the expected lifetime, rather than the system that is seemingly the cheapest when only the cost up to (and including) the commissioning phase is taken into consideration.

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TOWARDS A UNIVERSAL COMPUTER BASED LEVEL CROSSING PROTECTION SYSTEM

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***Abstract** – This paper deals with the analysis of existing Computer Based Level crossing – CBL-xing protection systems in different countries and for different cases of application. Various types of CBL-xing protection systems are analysed depending on the place of application: in railway stations and on the open track between stations (equipped with an automatic multiple blocks or with ordinary inter-station single block dependence). Numerous functions that depend on the signalling principles and practice in different countries and on the place of application on the track that contribute to the complexity and diversity of these systems have been analysed. Common functions that are necessary for all types of systems and for all applications are recognized and stated. Certain disadvantages of existing solutions in terms of their safety, hardware complexity, time required for design and execution and cost-effectiveness were also recognised. Based on the analysis and knowledge of how the CBL-xing system works, as well as their interfaces with other safety signalling systems, a proposal is made for a universal CBL-xing system a standard system, practically independent of the track layout and country of application. The proposal implies the implementation of the minimum necessary common functionality on the CBL-xing side, while all other necessary functions should be implemented within the appropriate safety signalling devices (like a station interlocking system) with which the CBL-xing is in dependency. The proposed CBL-xing system is an economical solution that also solves many of the above-mentioned disadvantages of existing solutions. Based on the above proposal, company Signalling & Control d.o.o., Belgrade has created one such CBL-xing called ELC (Electronic Level Crossing), which has been applied to the railways of Serbia for ten years.*

Keywords - computer-based level crossing, safety integrity level, electro-relay interlocking, safety analyses.

1. INTRODUCTION

Computer Based Level crossing – **CBL-xing** is a computer-based controlling and monitoring system, which ensures the crossing of the railway and the road. It is realised as modular and scalable - state of the art system for all types of the level crossings (on the single block line, on the line with automatic block and in the station area), for various signalling arrangements and for different railway authorities. CBL-xing usually has the highest safety integrity level (SIL4) in accordance with CENELEC Railway Standards [1].

2. TYPICAL CBL-XING APPLICATION

The typical track layout of a CBL-xing system for a single track application is shown in Figure 1.

CBL-xing contains inside and outside equipment. Inside equipment is realised in the controlling cabinet, which is placed at the hut near the crossing. It contains a power supply and the level crossing controller. Power supply (PS) usually contains two identical parts (PS1 and PS2) for availability. The controller is responsible for the safety of the system. Therefore, its CPU is realised as a 2 out of 2 (2oo2) system (duplicated for safety). Digital inputs and outputs – DIOs serve to connect remaining controlling equipment (flasher, detectors, relays, etc.) with the 2oo2 CPU.

Road related outside equipment is practically independent of the number of tracks and consists of: barriers machines with half booms (BB1 and BB2), road protection signals (RS1, RS2, RS3 and RS4) and warning bells (WB1 and WB2).

Railway related outside equipment is track and traffic direction dependent and for one bi-directional track usually consists of: train protection signals (TPS1 and TPS2), two pairs of switch-on elements

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(11/12 and 21/22) and two pairs of switch-off elements (31/32 and 41/42). Switch-on and switch-off elements and road signals are duplicated for the availability.

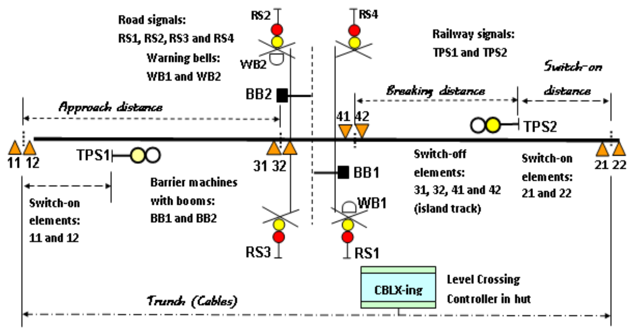

Fig.1. Typical track layout of a CBL-xing system

3. CBL-XING TYPICAL FUNCTIONS

During the long time of application of level crossing protection systems, the automatic half BBs became the most favourable and the most common as it offers an optimal result being a compromise between safety and performance [2].

Some of basic functions realised within CBL-xing protection system are listed below:

- Automatic activation (switching-on) / deactivation (switching-off) by occupation / release of switching-on / switching-off elements;
- Local Operation of Booms - LOB, i.e. activation / deactivation by the locally placed switch or key;
- Activation / deactivation via pushbuttons, with or without registration of use by counters, at signalman office (where applicable);
- Activation (switching-on) is not possible by the leaving train (Directional Stick Function is inbuilt);
- Designable advance warning time for BB and RS flashing lights (usually 15s);
- Designable maximum time of operation (closure) (usually 240s - 480s, typically 300s);
- Maximum time of operation is not applicable during the LOB operation;
- Automatic deactivation (switching-off) of the CBL-xing after maximum time of operation is exceeded;
- Detection of up and down positions and broken state of each BB;
- Designable maximum allowed time for dropping and lifting BB;
- Detection of correct work of the switching-on and switching-off elements;
- Detection of the correct work of the flesher;
- Detection of the protective state (down position of BB, flasher is operational, signal lights are operational and fault is not present);
- Designable time duration of the proceed aspect at the TPS (usually 30s-90s, typically 60s);
- Designable conditions to return the TPS to stop;
- Detection of work of TPS lights;
- Detection of works of RS lights;
- Detection of a Fault (safety critical failure, with registration of numbers by counters)
- Detection of a Disruption (failure with no impact to the safety, for example failure of one of the redundant elements);
- Fault and Disruption are retained until the failure is repaired and local push button is operated;
- Holding down function for the multiple track configurations for the multiple approaching trains;
- Functionality within automatic block or in the station area with the appropriate interfaces.

The Fault is detected in the following cases:

- Brake of a BB;
- One light of a RS is dark;
- Maximum time of the operation is exceeded;
- CBL-xing is not closed within the predefined time after it was switched on;
- One light of a TPS is dark;
- A flasher is not operational or the flashing rate (light / dark ratio) is irregular;
- Irregular operation of switching-on and switching-off elements;
- Irregular operation of BB;
- Battery voltage is below minimum allowed level;
- A 2oo2 CPU does not perform its function, i.e. it is in the stop state;

The Disruption is detected in the following cases:

- A Fault is detected;
- PS from the network (230V AC) is not present;
- One element from the redundant pair is not operational;
- Some time related functions are exceeded but bellow the critical time to detect a fault;
- If one filament is not operational, in the case that classical bulb is used as a signal light.

The Indication Panel (either conventional or computer based) can be placed locally and / or at the remote place to provide the appropriate states of the relevant elements of CBL-xing.

The following indications are provided:

- State of the switching-on / switching-off elements;
- State of the TPS lights;
- State of the RS lights;
- State of BB (up / down positions and broken);
- LOB operation status;
- Regular state (fault and disruptions not detected);
- Disruption state;
- Fault state.

4. COUNTRY SPECIFIC FUNCTIONALITY

Country specific functions depend on the signalling principles and practice in different countries

[3]. Position of a TPS varies and can be related to the service braking distance, emergency braking distance or some other distance related to the signal sighting and a braking distance. For all these cases the TPS clears with the detection of an approaching train. In general there are two main differences, which are related to the operation in the automatic block where an automatic block signal performs function of a TPS, or in the station area where a main signal performs function of TPS:

- English signalling practice:
  - TPS is at stop until the approaching train activates CBL-xing and then clears if CBL-xing is free of faults.
  - Train detection equipment (with time delay relays as needed) of interlocking and blocks uses for switch-on and switch-off functionality.
- German signalling practice:
  - TPS is clear all the time if CBL-xing is free of faults.
  - Additional switch-on and switch-off elements are used for the detection of trains.

There are advantages and disadvantages of both practice, but it is common that the TPS is not an independent signal belonging to the CBL-xing than a signal belonging to the automatic block or to the station interlocking. As a result, complex and application dependent interfaces are required between the CBL-xing and interlocking and blocks. This significantly increases time of realisation and cost of the CBL-xings.

5. PROPOSAL OF A UNIVERSAL CBL-XING

In accordance with the previous considerations, it seems reasonable to propose use of a universal CBL-xing system a standard system, practically independent of the track layout and country of application. The proposal implies the implementation of the minimum necessary common functionality on the CBL-xing side, while all other necessary functions should be implemented within the appropriate safety signalling devices (like a station interlocking system).

The universal CBL-xing system is an independent system and has the following main functions:

- In the station area:
  - Protected by the main signals at stop. Activates by the route setting commands. Deactivates automatically by the switch-off elements.
  - Manual activation and deactivation.
  - Has a standard simple interface with the interlocking, which includes above described commands and indications about the status of the CBL-xing (fault status and BB status, optionally RS status).
- Between the stations:
  - Protected by its own TPS signals at stop, which gives fault free information to the approaching train. Activates and deactivates automatically by the independent switch-on/switch-off elements.
  - Interfaces in general are not required. A train driver will report to the signalman if the TPS indicated faulty state of CBL-xing. The approaching train in this case follows a special procedure that usually includes stopping before the level crossing and slow passage.

The proposed CBL-xing system is an economical system that also solves many of the above-mentioned disadvantages of the existing solutions. Between stations it is completely autonomous without interfaces. In the station areas it has only simple and standard interfaces. Use of the TPS between stations contributes to the higher safety due to the reduced distance (time) between the TPS and level crossing.

Based on the above proposal, company Signalling & Control Ltd, Belgrade has created one such CBL-xing: **ELC** (Electronic Level Crossing), which has been applied to the railways of Serbia for ten years [4].

6. MAIN FEATURES OF THE ELC

ELC is realised as modular and scalable system with possibilities for the applications on various signalling arrangements and for different countries. Typical layout of the ELC controller is shown in Figure 2.

ELC is based on fail-safe **PLC** – *Programmable Logic Controller* of **HIMA** (HIMA Paul Hildebrandt GmbH + Co KG, Germany), which are certified for the highest safety integrity level SIL4 in accordance with CENELEC railway standards [1].

ELC is realised using high degree of modularity. They represent independent highly reliable functional units that are tested and approved for their purpose. Together they form the simple and low-cost hardware structure of the ELC, contributing to the generality, maintainability, higher reliability and safety.

ELC is typically realised for the applications in the extended temperature range from -25ºC to +70 ºC. It is designed for typical enclosure for inside mounting (level crossing hut). Therefore, it does not require additional insulation of the equipment house nor additional heating and cooling equipment. This significantly reduces the power consumption. As a result, the total power supply for the complete (inside and outside) typical ELC solution is under 250W.

Rectifying part of the power supply is realised as a highly reliable single channel structure with battery (long life and maintenance free) backup (minimum 8h), but two pairs of internal and external DC/DC convertors (also highly reliable) are used for the power supply of the internal and external elements.

As a switch-on and switch-off elements practically all known devices for this purpose, such as: electronic rail contacts, inductive while detectors, inductive loops, short range track circuits, long range track circuits, conventional track circuits, axle counters, etc, can be used. It is enough to provide the element state through a voltage free contact. From safety reasons it is sufficient to use single switch-on and switch-off elements, but they can be duplicated for the availability if required.

Fig.2. Controlling cabinet of the ELC system

ELC can use various types of the boom barrier mechanisms, which are approved for use from the relevant railway administrations. It is necessary to provide data about the up and down position and broken state of a boom barrier by the appropriate voltage free contacts. Other relevant functions, including time of lowering and rising of booms are covered by the application software.

ELC supports use of various types of the light modules for RS and TPS, such as conventional bulbs and LED modules (typical use due to the high reliability and low power consumption). The system uses current detection modules with adjustable levels for detection of the current of the LED modules (or main and the auxiliary filaments of classical bulbs).

Electronic flasher is realised as an external, high reliable hardware module with solid-state relays - SSR output with adjustable light and dark phase (typically 50% / 50%). It is continuously monitored by safety PLC. Flasher is realised as a modular and scalable unit and the output SSR are duplicated for the availability.

Minimal necessary number of highly reliable miniature safety relays is used for the interfaces between outside equipment and DIOs of the central PLC system. The conventional safety techniques such as "de-energised state is safe" and back contacts proving are used to insure safety of the interfaces.

The outside equipment is connected to the inside controlling cabinet via lighting (overvoltage) protection modules - LPM, which have disconnection terminals from both sides for easier measuring, and checking and faster testing and commissioning.

The application software is realised by the appropriate functional modules, with designable parameters adjusted to the specific application. During the factory acceptance test - FAT with the realistic simulation of the outside equipment complete functionality is tested. As a result, sight acceptance test - SAT is significantly simplified and practically reduced to test of correspondence of the required elements (commands and status). This contributes to the efficient testing and commissioning.

ELS system is supported by an advanced SD&ER – Service, Diagnostic and Event Recording system. Also with the GSM module, which sends SMS related to the ELC state to the signalman, maintenance staff, dispatcher, etc.

7. CONCLUSION

The ELC is realised as a safety controller of universal type, which covers functionality of an automatic level crossing with half barriers for all types of the track layouts and various types of the outside equipment. It is maintenance friendly. It has very high reliability and very low power consumption.

ELC is also an economical system, highly competitive with both CBL-xing and conventional, relay-based, level crossing protection systems.

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APPLICATION OF MACHINE LEARNING IN THE ANALYSIS OF THE WEB PROXY SERVER IN RAILWAY TRAFFIC ENVIRONMENT

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Abstract – *The introduction of machine learning and anomaly detection classifiers in the process of supervision in the IT industry, opens up a new dimension in traffic analytics and decision-making for interventions in short periods. Case, described in his paper, needed a proxy server control for certain clients in the intranet network, clients in the traffic and transportation domain. The importance of those positions lies in the fact that the operation and control of traffic processes on the railway are monitored through these workstations. Since the National CERT of the Republic of Serbia issued a notice about possible threats via the Internet to users who have the Any Desk application on their workstations, the task was to analyze whether there is such a case with predefined workstations. The paper includes the analysis of event records from the proxy server using the Weka software package with the J48 classifier. The analysis included reports from the Weka program using a decision tree and the appropriate classifier.*

Keywords – WEKA, decision tree, proxy server, railway staff.

1. INTRODUCTION

Data analysis using classifiers and decision trees still has applications in machine learning, although new techniques are coming along over time. The work deals with the use of the J48 classifier in the analysis of data from the Proxy web server, in order to detect flaws in the blocking of the Any Desk software package on computers used by traffic officers, related to the text of the National CERT regarding the announcement that old versions of the software are not stable, i.e. they are dangerous to use.

2. SOFTWARE TOOLS

The software package Weka, which stands for "Waikato Environment for Knowledge Analysis", was used for data analysis and machine learning algorithms [1]. The software is defined as open-source and is under the GNU (General Public License) license, which enables the use, modification and sharing of the software with other users. Weka, as a software tool, has survived various additions and modifications, but still, in the world of machine learning, it occupies a position due to the easy and logical use of the software. Weka is a software tool whose function is data mining. To successfully search, that is, perform data mining, the software tool must have certain modules for preparation, classification, regression, grouping and visualisation of data. The input data set on which a type of machine learning is applied, as a result of which a decision tree is built, is called a training data set (eng. training set). Comparing different types of machine learning over the same training data set is used to determine learning performance. Algorithm J48 belongs to the algorithms that build a classification model from the data for training the system using decision trees. The algorithm strategy itself is top-down, meaning it defines the first attribute and then creates branches for each attribute value. The advantages of the decision tree are ease of understanding, simplicity, and working with different types of data [2-5]. The algorithm starts with the original node as the base node. At each iteration, the algorithm iterates through each unused attribute of the set and calculates the informational gain of that attribute. After that, it chooses the attribute with the lowest entropy and the highest value of information gain. Here entropia means a measure of uncertainty in a data set.

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The basic formula for entropy calculation (1) is:

$$H(S) = \sum_{x \in X} -p(x) log_2 p(x) \quad (1)$$

where S is the current data set over which entropy is calculated, X is the set of classes S, p(x) is the ratio of the number of elements in class x to the number of elements in set S.

Entropy, in information theory, measures how much information is expected to be it is obtained by measuring a random variable and as such can be used to quantify the quantity up to which the distribution of the value of the quantity is unknown. For example, a constant variable has zero entropy, while a uniformly distributed random variable has maximum entropy. The information gain measures the difference in entropy between the state before and after set S, which is divided into attribute A. The information gain is calculated according to the following formula (2):

$$IG(S, A) = H(S) - \sum_{t \in T} p(t) H(t) = H(S) - H(S|A) \quad (2)$$

where H(S) is the entropy of the set, T is the subset created by dividing the set into attributes, p(t) is the ratio of the number of elements in t to the number of elements in the set S, H(t) is the entropy of the subset t.

Evaluating the value of the classifier allows for defining the best classifier. Some of the methods used for this purpose are:

- Test sample method
- Method of cross-assessment

The test sample method divides the data set into two parts. The first part is the dataset that will be used for training, while the second will be used for testing. 33% of the total data is usually taken to assess the accuracy of the prediction. The accuracy score is a random number that directly depends on dividing the data set into training and test data sets. The procedure is repeated k times, and the accuracy can be obtained as the mean value. The prediction accuracy can be increased by increasing the number of samples in the training set. Figure 1 shows a model of data processing using model training and subsequent sampling with another set of data [4].

The quality of the qualification model cannot be defined by a single value. For this purpose, a graphical representation via the ROC (Receiver Operating Characteristic) curve is used. Sensitivity and specificity are two measures that characterise a classifier's specific accuracy.

The vertical axis of the ROC curve indicates the number of true positive samples, while the horizontal axis indicates the number of false positive samples, as shown in Figure 2 [6].

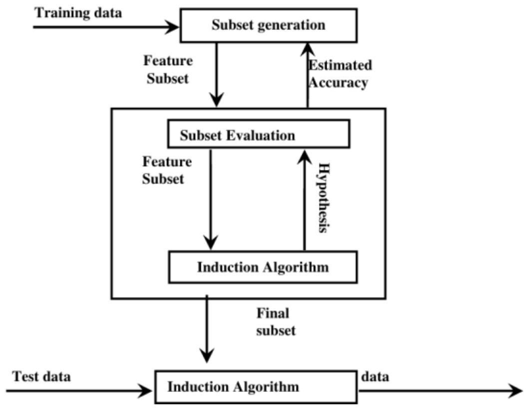

Fig. 1. A model of working with data [4]

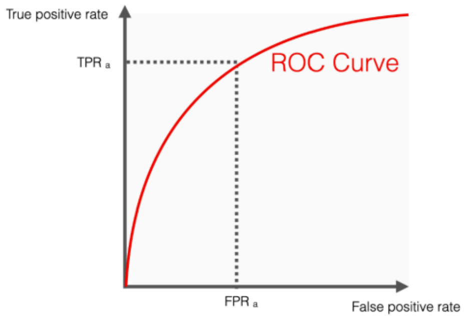

Fig. 2. ROC curve model [6]

3. DATA SET PREVIEW

The data used in the work were obtained from the central WEB Proxy server. The proxy server can centralise Internet access for workstations in the Intranet network. Each exit is recorded with a corresponding log and follows the server policies defined on the device and following the business policy [7,8]. In the example given in the paper, the operation of the new Proxy server was tested, but with the option that server policies were not activated. The proxy server is uploaded to the traffic dispatchers' workstations through the Microsoft Active Directory server policies. The corresponding figure for the system under analysis is given in Figure 3.

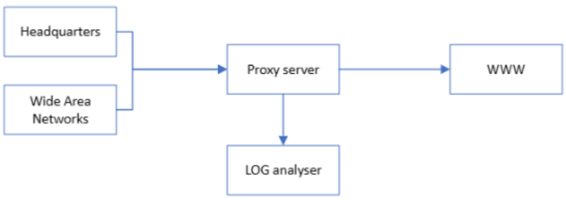

Fig. 3. Network model

For work and analysis of traffic to sites that are not allowed in the business environment, the following fields were selected as attributes for further analysis:

Duration is the time defined on the Proxy server and indicates the time it takes for the server to process the transaction session. This attribute can help us see the proxy server's usage for certain services. The following attribute values were defined for the analysis, as shown in Table 1. For the sake of a better display and easier data processing, the classification was made into four groups in relation to the duration of the session.

Client IP is the client's address that initiates the session to the Internet. In our case, we look at two ranges of addresses, shown in Table 2. The basic ranges are workstations from the administration building and the range of workstations from the rest of the intranet network. The division was made based on the number of computers and sessions to facilitate later detection of problems in the system.

Tab. 1. View classified attribute Duration

Attribute lebel	Quantity	Value range
A	218005	0-1 msec
B	121598	1-500 msec
C	167779	500-4.000.000 msec
D	69317	100.000-4.000.000 msec

Tab. 2. Range view for client workstations (IP)

Attribute lebel	Quantity	Value range
HQ	281991	IP addresses of workstations located in the administrative building
WAN	225391	IP addresses of workstations located in the field, by railway stations and facilities

Tab. 3. Display of attribute values for the destination

Attribute lebel	Quantity	Value range
AnyDesk	11998	Remote computer access
Facebook	6363	Social network
Google	38078	Google services
Microsoft	100842	Microsoft services
Ostalo	350101	Other services

Tab. 4. Display of attributes for session type

Attribute lebel	Quantity	Value range
App	3064	Defined applications used for Office business
Media	82210	Audio and Video Production
P2P	179183	Direct communication and data exchange between server and client
Tekst	242925	Textual content

Tab. 5. Display of session result attributes

Attribute lebel	Quantity	Value range
Cache	91311	Content is cached on the server
Denied	239448	Content has been rejected
Tunnel	176623	Content is tunnelled

URL (Uniform Resource Locator)—is an attribute that indicates the destination address of the client request. For the purposes of the analysis, the URL attribute values were defined as shown in Table 3. The emphasis is on the application that was detected as problematic.

Type—is an attribute that more closely determines the type of content exchanged between the client and the server. Considering the problem, all data are grouped as indicated in Table 4.

The resulting code is an attribute that gives the exact output model, indicating whether the session is rejected, whether the traffic is tunnelled directly to the server, or whether the content is taken from the local cache. The attribute values are shown in Table 5.

4. MODEL ANALYSIS

For the analysis of the data set, as stated, we will use the software package Weka, as well as the corresponding algorithm J48, through the analysis of the decision tree. Given that we have a data set of 507382 records, we will divide it into two sets; that is, we will define within the Weka software the division into 60% of the data set for training and 40% of the data set for test, as shown in Figure 4.

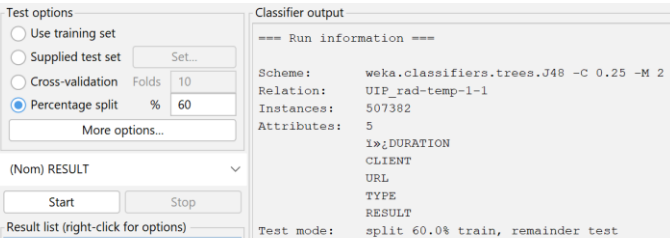

Fig. 4. Representation of the data set partitioning.

By running the J48 algorithm through the defined 60/40 data division, we get the following results in sum:

- 201177 correctly classified instances, about 99.1249% of the total test sets.
- Incorrectly classified instances 1776, about 0.8751% of the total test sets.

The confusion matrix is shown in Table 6. Other data, for deeper model analysis, for the J48 classifier are given in Table 7.

The accuracy classification of the model is confirmed by the ROC (Receiver Operating Characteristic Curve) Area values, which in our case is quite high. This means that the model can make predictions in a very high percentage. The graphical indicator of accuracy is the area under the ROC curve. The display of the ROC curve for the attribute Results, value Denied, is given in Figure 5.

After inspecting the decision tree, it can be determined that, in the interesting example, an application that is not allowed is detected in the tree and blocked, as shown in Figure 6.

Tab. 6. Elements of confusion matrix

a	b	c	
35321	785	402	a = Cashe
219	95115	368	b = Denied
2	0	70741	c = Tunnel

Tab. 7. Overview of model values with classifier J48

TP Rate	FP Rate	Precision	Recall	Class
0.967	0.001	0.994	0.967	Cashe
0.994	0.007	0.992	0.994	Denied
1.000	0.006	0.989	1.000	Tunnel
0.991	0.006	0.991	0.991	Avg.
F-Measure	**MCC**	**ROC Area**	**PRC Area**	**Class**
0.980	0.976	0.995	0.989	Cashe
0.993	0.986	0.998	0.997	Denied
0.995	0.992	0.998	0.992	Tunnel
0.991	0.986	0.997	0.994	Avg.

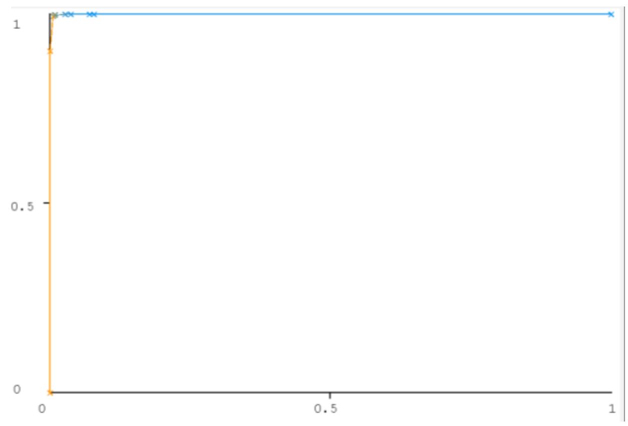

Fig. 5. ROC curve for the value of the Denied attribute Results

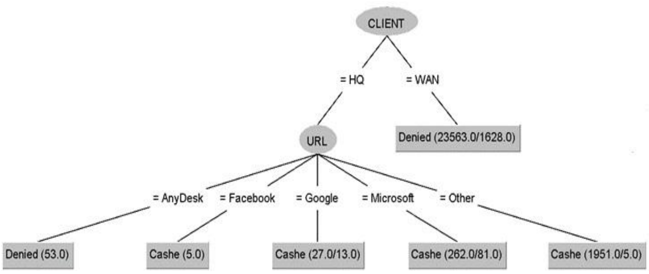

Fig. 6. Rejection of AnyDesk instance URL attribute

5. CONCLUSION

This paper disscused the principle of the Proxy server analysis and the possibility of events prediction using the Weka software package for machine learning and the J48 classifier were reviewed. The data used are real data, which do not often contain some undetermined values. In this case, we have mostly good data because the values for poorly classified values are around 0.875%, which is not a high value. The accuracy of well-classified data is 99.1249%, which is an extremely high percentage. By showing the confusion matrix and calculating the corresponding variables, TP, FP, TN and FN, we get that the model's accuracy is 0.991 as an average value, looking at the values of the Results attribute. Also, the value for ROC is 0.997, which represents a high value. By displaying the decision tree, it can be seen that the functionality of the Proxy server is completely mapped onto the tree. The main function was to predict and prove that certain applications, which are prohibited for certain employees of the traffic service, cannot be used. The tree clearly shows that those requests to use the prohibited application were rejected.

The next step in event prediction research could be choosing other classifiers, comparing different classifiers and selecting those whose accuracy would be higher than the one currently processed. Also, instead of one data set, it is preferable to use two data sets, one for training and the other for testing. The last type of analysis would be the adjustment of the model when the data sets were taken from different time intervals and for different days during the working week.

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RAILWAY TRANSPORTATION AS A CAUSE OF CADMIUM POLLUTION

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Abstract *– A number of current studies have revealed that during regular railway operations, different kinds of heavy metals accumulate on the track and in the railway body. Cadmium stands out among pollutants, both in terms of the amount of excess and in terms of the severe harm it causes to human life and health. In the first place, the study discusses existing methodologies for detecting the presence of heavy metals in soil on the railway body or in the surrounding areas. Following current procedures, the results of individual study were discussed and compared to those of other researchers. The individual study was done considering a section along a railway in service, which verified that cadmium was present on the railroad. In addition, various sources and origins of cadmium were analyzed considering the railway transportation. All the presented researches imposed an urgent need to establish effective remediation measures against the harmful impact of cadmium.*

Keywords - railway pollution, environment, heavy metals, cadmium.

1. INTRODUCTION

The significance of railway traffic in terms of transporting people and goods is enormous. It was expected that, in order to reduce the emission of gases with the greenhouse effect, this mode of transportation could take the lead, particularly in the promotion of passenger transport considering the rise in the number of people who travel for work.

The increased use of railways does not necessarily imply that harmful substance emissions into the environment could be avoided. Studies upon the impact of railway traffic on the quality of soil and water in nearby areas of railway routes, have discovered the presence of heavy metals, with cadmium (Cd) standing out as an extremely dangerous metal for human life and health [1, 2]. Cadmium may enter the human food chain in a variety of ways, including through contaminated agricultural land or drinking water sources [3].

In the case of railway transport, the release of pollutants into the environment was simplified since, as the rainwater was transported away from the railway structure, all pollutants flowed into the channels and were delivered to the recipient. During runoff, infiltration into the soil is inevitable. In this way, by gradual infiltration of Cd into the surrounding soil, which is often agricultural, it easily reaches the groundwater [4].

In order to test the soil near the railway track and find out if any hazardous heavy metals were present, this paper gave an outline of the methods that were actually employed [2], [5-7]. Additional details were provided on the findings of the analysis of Cd concentration in the railway embankment using two widely recognized techniques, XRF and ICP-OES [8]. The significance of choosing an appropriate testing method, focusing on the findings of evaluating the concentration of Cd in the railway line's body

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paper, was highlighted. Values and positions of Cd spreading over the railway body's cross section were highly consistent throughout its depth.

Several particular findings on the origins of Cd were discussed below [7, 9, 10]. Examining the origins of Cd is crucial since obtaining this information may make it possible to reduce the excessive amount of the heavy metal released into the environment.

2. CADMIUM TOXYCITY AND HEALTH RISK

The International Agency for Research on Cancer (IARC) has classified cadmium and cadmium compounds as carcinogenic to humans [11]. Among the health issues they might cause, the kidney failure (tubular dysfunction and nephropathy), disturbances in calcium metabolism (osteomalacia and osteoporosis), lung changes (lung cancer and chronic obstructive pulmonary disease) and liver function are particularly noteworthy [4, 12].

Although the heart and brain tissues are not the first to be affected by Cd, they suffer immediate effects and might result in intoxication and death [13]. Human intoxication with Cd causes vascular tissue damages, atherosclerosis, hypertension, but also leads to Peripheral Arterial Disease and Conorary Hearth Diesase. During some initial examinations into the influence of cadmium on human health, several occurrences were identified, such as tremors, sweating, dermographia, increased-knee joint reflexes, altered neuromuscular conduction and optic and sensory disorders. Compared to impacts on the cardiovascular system, neurotoxicity can cause a larger range of symptoms, including headache, visual problems, slowed vasomotor functioning, peripheral neuropathy, disturbed balance and difficulty concentrating. In addition to the above-mentioned consequences, there is a detrimental influence on human's reproductive health [14].

The aforementioned disorders are often induced by consumption of contaminated food and water, where cadmium has entered the human food chain through recognized or undiscovered ways [3].

3. METHODS FOR CADMIUM DETECTION IN RAILWAY BODY TRACK

For the purposes of determining the concentration of Cd in the railway body, several methods were considered. All available test results, specifically related to the concentration of heavy metals in the soil near the railway track, were searched. It was about testing of soil in the railway body and the surrounding area.

According to the searched methods, the X-ray fluorescence spectrometry (XRF) stood out. Besides being the most commonly used technique, operator training takes little effort and it is simple to understand. It is recommended that the recording should be done on processed, ie. dried and crushed, sample in order to obtain the most homogeneous sample possible [8]. Furthermore, the recording might be done "in city". In that instance, it is crucial that the recording site is free of any obstacles so that access to the content being inspected is guaranteed. The area must be clean of vegetation or garbage so the device has direct contact with the material being tested. Based on existing research, concerning railway traffic influence on environment, XRF identified a wider range of heavy metals, including Cd [7].

The microwave plasma-atomic emission spectroscopy (MP-AES) was also employed in the published experiments for heavy metal detection in the soil along the railroad line. Microwave plasma-atomic emission spectroscopy has shown to be successful and widely used technique, for heavy metals identification in a variety of materials [7].

A couple of cases of inductively coupled plasma-optical emission spectrometry (ICP-OES) were observed in the investigation of the concentration of heavy metals in the railway area [5]. Identical to MP-AES, this approach is more reliable as it, with a wide range of applications. The ICP-OES method is similar to MP-AES, with the difference that ICP-OES uses argon plasma instead of nitrogen plasma (MP-AES) [6]. Along with ICP-OES and MP-AES, inductively coupled plasma-mass spectrometry (ICP-MS) was applied to evaluate the impact of rail traffic on heavy metal pollution [2]. In addition to material sampling, special preparation of the same is required before testing in spectometer. The preparation of the material should be done with the help of a professional associate who operates the spectrometer.

In this particular case, discussed in the paper, two techniques were run simultaneously to determine the presence of cadmium in the railway body: XRF and ICP-OES [8]. The examination of the concentration of heavy metals in the railway body was carried out using the ICP-OES spectrometer (iCAP 6000 series, manufactured by Thermo scientific company) with the operating parameters listed in Table 1. The preparation of the samples was done in compliance with the ICP-OES test protocol. As indicated in Table 2, sampling was conducted on two cross-sections and particular locations.

Significant observations were made regarding the results. According to the results, Cd was singled out due to multiple exceedances. The measured value ranged from 4,2 ppm to 7,1 ppm (Table 2). The maximum allowed value according to Maximum allowable concetration (MAC) prescribed for the Republic of Serbia was exceeded 5,5 to 8,9 times, since maximum allowed value was 0.8 ppm [15].

According to EU Directive document, permited value of 1.0 ppm was exeeded 4,4 to 7,1 times [16].

Tab. 1. Operating parameters for ICP-OES spectrometer

RF power (W)	1150
Analysis pump rate (rmp)	50
Flusc pump rate (rmp)	100
Nebulazer gas flow rate (L/m)	0.7
Coolant gas flow rate (L/m)	12
Auxilliary gas flow rate (L/m)	0.5
Observation mode	axial
Rinse time (s)	30

Tab. 2. Values of Cd in the sampled position of cross-section 1 and cross-section 2 obtained by ICP-OES

	Sample location	**Cd** [ppm]
cross-section 1	Track axis	5.1
	Track axis (1.3m depth)	5.1
	Foot of the ballast (left)	5.6
	Foot of the balast (right)	4.6
	Foot of the ballast (left, 1.3m depth)	4.4
	Foot of the ballast (right, 1.3m depth)	5.0
	Channel (left)	5.3
	Channel (right)	4.2
cross-section 2	Track axis	5.8
	Track axis (1.3m depth)	6.0
	Foot of the ballast (left)	5.4
	Foot of the balast (right)	7.1
	Foot of the ballast (left, 1.3m depth)	5.6
	Foot of the ballast (right, 1.3m depth)	5.3
	Channel (left)	5.4
	Channel (right)	5.8

Samples scanning was performed using the hand held analyzer made by LANScientific, model RTU-XRF7460. According to specification, the device was provided for detection of heavy metals in the soil on samples in the solid state, as dust, powder, soil clods or even thin layers of soil, with the Mg-U detection range [17].

The same samples were utilized for both technique, ICP-OES and XRF. It was detected 35 kinds of metal and among them a lot of hazardous heavy metals. Namely, the presence of Cd was not detected by the XRF procedure. Comparing the results of this testing with the results published by Samarska (2020), the most of main-filter and high-filter elements coincided, except Cd.

For unknown reasons, none of the 16 samples had cadmium found in them by the XRF instrument, indicated above. Whether in this case the characteristics and range of the device were not adequate for detecting cadmium in the material or there are other reasons, was impossible to debate. The presence of cadmium in the aforementioned samples was confirmed by the ICP-OES analysis. It is evident that, even with a widely used technology like XRF, study should never be limited to a single approach in the case of such delicate studies, especially when it comes to a particularly poisonous metal.

4. POSSIBLE SOURCES OF CADMIUM ON RAILWAY LINE

Considering the possible sources of cadmium, two obvious options arise. Cadmium in its natural state originates in volcanic stones [9]. This kind of stones are recommended for use in the construction of ballast to provide a stable support for the railway, maintain track geometry and adjust elasticity and stiffness of the track structure [10, 18]. The possibility that the ballast itself is one of the causes cannot be excluded. Ballast is a layer exposed to great static and dynamic influences and its crushing occurs. It is the element of the track that is most exposed to washing by stormwater, where crushed particles can easily reach the lower layers of the track body and drainage channels.

Generally speaking, excessive traffic is another potential cause of cadmium contamination [9]. This covers a variety of issues, including applying herbicides, lubricating machinery during usage and galvanizing metal components [7].

Upon examination of the aforementioned potential sources of cadmium, it is evident that they are wholly associated with components and procedures related to railway exploatation. It is impossible to envision railway traffic without any of these components, which makes the issue even more concerning because there is no way to eradicate Cd by removing the source.

5. CONCLUSION

Research on environmental contamination caused by train activity is becoming increasingly common and diversified. The paper mentions a couple of techniques able to detect and measure the amount of cadmium specifically in the body of the railway track, but also in the soil surrounding it. Each of the methods is distinguished by certain characteristics and in this connection, some more or less require the training of the researcher. The XRF scanning procedure is certainly most simple to use and does not require any specific knowledge of chemical bonding or principles. A completely different kind of techniques are methods such as ICP-OES, MS-AES and ICP-MS. In particular, the ICP-OES spectrometer, although it belongs to the group of more demanding techniques, proved to be more reliable in detecting Cd in the case when XRF failed to determine the presence of Cd, no mention to measure the amount.

The reasons for this result were not clear after testing nor after comparing with the results of other researchers who properly determined the presence of Cd using XRF devices. Due to the easier applicability and speed of obtaining results using XRF, it is necessary to determine factors affecting whether cadmium will be registered. This is not about the accuracy of measuring the amount, but about not detecting it at all.

The general conclusion, drawn on the basis of the above-mentioned research results, would certainly be that with sensitive substances, such as cadmium, the investigation should never be reduced to one method. Also, considering information about Cd origins, the construction of railways may be approached differently in an effort to reduce the discharge of heavy metals, particularly cadmium, into the environment.

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OVERVIEW OF METHODS FOR DETERMINING THE CAPACITY OF THE RAILWAY NETWORK

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Abstract – *The throughput and transport capacities of the railway sections, lines and network are characteristic technical and operational indicators showing the technical and organizational capabilities of the specified elements of railway transport for the realization of the volume of transported work. The report provides an overview of the methods used to determine the throughput on the railway network. The throughput capacity of a specific railway section was analyzed in connection with the ongoing and upcoming works on the implementation of a number of investment projects in the railway infrastructure and implementation of the ERTMS/ETCS system.*

Keywords – railway infrastructure, railway network, throughput and transport capacities.

1. INTRODUCTION

Rail capacity is a critical aspect for the efficiency and reliability of the transport network. It includes the ability of rail infrastructure to support a certain volume of traffic for a given period of time. Capacity analysis is important for planning, managing and optimizing rail operations. It has an impact on the Train Timetable (VGS). According to various characteristics, an optimal GDV is prepared. Using different models and simulation software can help model different scenarios and estimate capacity under different conditions.

2. OVERVIEW OF RESEARCH IN THE FIELD. THROUGHPUT AND TRANSPORT CAPACITY

There are several main aspects of the throughput and carrying capacity of railway elements [1][2][3]:

- maximum throughput and transport capacity;
- necessary throughput and transport capacities for the proposed volume of railway transport work.
- The available throughput is that available to the operational element at a given time;
- Capacity reserve is the difference between the maximum and required throughput.

The maximum capacity of a railway section in question, of a track or of another operational element of the railway network is the maximum number of trains of a certain weight (composition) that can pass this element per day or other period of time considered, depending on the existing technical equipment, type and type of locomotive and the system for passing trains under this element.

The maximum carrying capacity of a track, railway section or other operational element of the railway network shall be the maximum number of net or gross tonnes that may be omitted in a year or other period considered, also depending on the evolution of the capabilities of the mobile vehicles, the qualification of personnel and the use of technical means.

In all cases, a specified maximum capacity and certain parameters of mobile vehicles corresponds to a specified maximum transport capacity.

The main elements by which the maximum capacity is determined for a certain period of time considered are railway interstations, sections, stations and lines [2][4].

The required throughput is the number of trains (wagons) obtained at the parameters of maximum throughput, depending on the proposed volume of transportation for a considered, realized or planned period of time, for which it is determined.

The determination of the specified types of throughput and transport capacities should be done depending on the different types of progressive technologies and ways of traffic organization, using variant schemes, as well as relevant modern methodologies [18].

The maximum throughput shall be determined by the following formula:

$$N_M = \frac{A - A_{ПОСТ}}{a} \qquad (1)$$

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trains (or pairs of trains) where:

A-total resource (opportunity);

Apost – part of the resource that is needed for the needs of this device or for other devices not directly related to the passage of trains, in the same units of measurement;

a – expenditure of the same resource for the realization of the passage of one train or pairs of trains, respectively, or of a group of trains with a certain uniform frequency of passage.

The available throughput is that available to the operational element at a given time;

Capacity reserve is the difference between the maximum and required throughput.

The types of throughput and transport capacity are presented in works [1][2][6][7][8] [9].

2.1. Impact of capacity and transport capacity on train traffic organisation

The organization of train traffic is realized on the railway lines on the basis of a pre-developed and approved schedule. It reflects the number of trains, the times of their arrival, departure or transit through the stations, the times of their movements in the interstations, the tying of their locomotives in the stations, the interruption of movements in the interstations, the work of all operating units of the railway transport.

In order to carry out the correct organization of train movement, a train schedule is drawn up, based on preliminary optimization for each section and each railway line. On the basis of it, the timetables of the individual trains shall be determined, indicating at each of them and for each station and stop the times of arrival, transit and departure, inter-station distances, permissible speeds on the elements of the railway line, the inter-station travel times of trains and the meetings or exceedances of each train at the stations with the other trains, respectively. The methods are described and discussed in detail in works [1][6][10][11][12][13]. In the works of [2][3][14][15][16][17]18][19] [20] and [21] are described types of train schedules, according to different characteristics.

2.2. Impact of maximum capacity on train schedules

Methods and approaches for determining the maximum throughput depending on the main influencing factors are presented in works [2][6][7][8][9][10][11] [12][13][22][23].

The maximum throughput and carrying capacity of railway interstations and sections, depending on the main influencing factors, mainly the different types of train schedules and the schemes for their passage, the ways of ensuring the movement of trains in the interstations and stations leads to the determination of:

A) The maximum capacity of single-track (single) interstations under a simple parallel traffic schedule [2].

(B) Maximum throughput on a non-paired parallel traffic schedule [2].

C) Maximum throughput for parallel paired package and partial-batch traffic schedules [2].

E) Capacity of sections with one-way and double-track interstations and elements in parallel paired traffic schedule.

F) Maximum capacity of double-track interstations in parallel train schedule.

(G) Maximum capacity of railway sections with a non-parallel paired train schedule.

Studies of the throughput capacity of the railway network in Bulgaria under different conditions have been made in the following works: [1][6][7][8] [17][24]. At work [18] the unevenness of the movement of freight trains in one section has been studied.

2.3. Main factors affecting throughput

Infrastructure elements:

- Research shows that multi-track and double-track lines significantly increase capacity compared to single-track lines [27].
- Advanced signalling systems such as ETCS Level 2 allow for shorter intervals between trains, increasing capacity [28].

Operational practices:

- An effective timetable can minimize downtime and increase capacity utilization. Various studies look at timetable optimization algorithms that balance between passenger and freight trains [29].
- Motion Control:
- Real-time traffic management and dynamic timetable adjustment are key to capacity optimization [30].

Technical characteristics of the rolling stock:

- Faster trains with better acceleration characteristics can increase capacity by reducing travel times and increasing the number of trains that can use the infrastructure for a given period [27].

2.4. Case studies

The European Rail Traffic Management System (ERTMS) has been introduced in many countries to increase capacity and safety. Research shows that ERTMS Level 2 allows for shorter intervals between trains and increases capacity by up to 40 [31].

Japan's Shinkansen high-speed train system demonstrates high throughput thanks to specialized lines and strict schedule control. Research shows that Shinkansen lines can support up to 14 trains per hour in one direction [32].

In the United States, where freight transport dominates, research has focused on route optimization and train planning to increase capacity. Big Data Simulation and Analytics Models Are Used to Improve Efficiency [33].

3. IMPACT OF CAPACITY ON TRAFFIC BETWEEN BULGARIA AND TURKEY

Throughput plays an important role in the current state of railway transport in our country. The rehabilitation and modernization of major railway lines in Bulgaria leads to strong traffic restrictions. Due to its geographical location, a large cargo flow from Asia to Europe passes through our country. Currently, the border between Bulgaria and Turkey is served by only one border checkpoint - Kapikule-Svilengrad. Prepared traffic forecasts show an upcoming increase in freight traffic across our border. In addition to the connection between Asia and Western Europe, between Bulgaria and Turkey, after the outbreak of the war in Ukraine, a new route of connection from Asia to Ukraine and the eastern parts of Europe is being sought, which again leads its way through our country. For the movement of trains between Turkey and Romania, at the moment the transport must pass between Dimitrovgrad and Gorna Oryahovitsa, where, however, the throughput capacity is 30 trains, and in some places it is even more limited. The only option for the passage of trains at the moment is through Mihaylovo - Karnobat - Sindel - Ruse. With this detoured route, the distance is 168 km. This leads to a search for solutions for easier and faster traffic. Such an option is the construction of the line Yambol - Elhovo - Lesovo - Edirne. It shortens the distance to 80 km, and in addition to The shorter route, when building a completely new line, will be able to comply with all European requirements and to implement all new technologies and requirements of the European Union. An analysis shows that in the presence of such a line, the traffic of goods between Southeastern Bulgaria and Turkey will also increase. The construction of this line will also be in accordance with the requirements for necessary and maximum throughput, with a sufficient reserve to be used in the expected increase in the cargo flow along this route. It will also facilitate customs activities at border stations.

4. CONCLUSION

A literature analysis of rail capacity reveals that efficient management and modernization of infrastructure are key to increasing capacity. The research and methods presented in the literature provide a rich set of tools and strategies that can be applied to optimize rail operations and improve both passenger and freight transport services.

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POSSIBLE SCENARIO FOR VOIP COLLABORATION SOLUTION IN RAILWAY ENVIRONMENT

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Abstract *– Collaboration solutions for corporate level are transforming and migrating, taking the best possible properties from all the contemporary ICT solutions have to offer. Railway companies consisting of infrastructure/freight/ passenger subdivisions could potentially benefit from all the collaboration vendors are implementing, Multiple transmission and communication platforms integrated in both administrative and traffic domains in railways are changing and it is sometimes unclear are railway applications loosing in this race. Scenario discussed in this paper could indicate a long-term platform evolving at the needed rate, overcoming hybrid periods easily, day-to-day migration of employees and divergence in personnel distribution.*

Keywords – railway telephony systems, cloud-based solutions, unified communication.

1. INTRODUCTION

Communication between railway staff is crucial in traffic management and has always had an important position in the regulations for the exact definition of communication rules, both in domestic and international communication, at border crossings [1,2]. Of course, modernization and technical-technological innovations had to affect this segment of telecommunications as well. The question arises to what extent the VoIP systems should be interleaved with other communication technologies in railway, and whether there is a limit that should be set in order to ensure reliable and controlled communications.

2. VOIP IN RAILWAY ENVIRONMENT

Generally speaking, in railway traffic, VOIP communication exists between the staff along the track and the dispatcher, between the dispatchers themselves, between the train driver and the dispatcher, between the track workers and the dispatcher by all possible systems.

Many systems are defined as closed systems, i.e. systems that do not communicate with other systems, and are also implemented as systems with their own transmission systems. The modernization of the transmission system led to the migration of various services into a single transmission system.

Another system, MPLS (Multiprotocol Label Switching), enables high speeds with redundant links. This can set the first level of modernization of the VoIP system, i.e. the traditional relay systems (Fig.1), on old transmission systems can be replaced with a classic TCP/IP based server structure with corresponding transmission systems with enough capacity for evolving services.

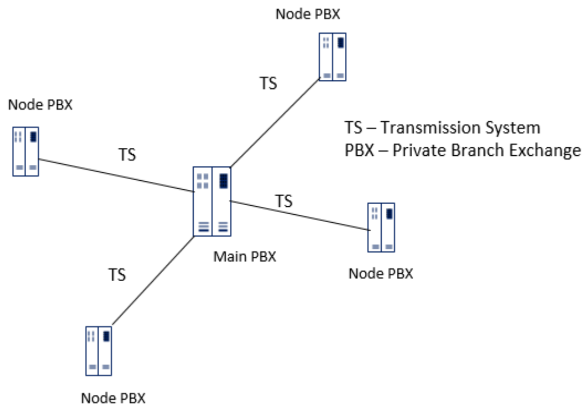

Fig.1. Starting point with old systems

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The VoIP system organization principles, the definition of the transit exchange, the main exchange (Private Branch Exchange PBX) and the node PBX, still, remains defined for the reason that the entire network could not immediately switch to MPLS connectivity [3]. Switching the entire network to MPLS involves the entire optical structure along the railway, which is essentially a large investment.

The next level of VoIP system development is directly dependent on the development and expansion of the transport system. In order to ensure higher speed, connectivity and redundancy for locations, where the nodal PBX is located, the introduction of advanced systems such as L3VPN (Level 3 Virtual Privet Network) as well as IPSec (IP Security) tunnels over a standard Internet link is mandatory (Fig.2.). If these two options are included, for stations/locations that do not have MPLS connectivity, a good option would be to install SD-WAN (Software Defined Wide Area Network) technology. A model of such a connection is given in the Fig.3.

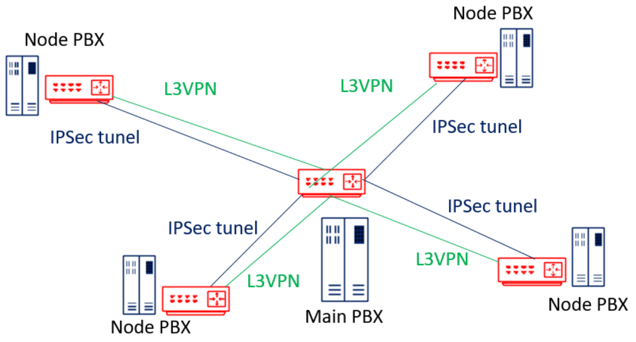

Fig.2. Second phase, with redundant links and old PBX network

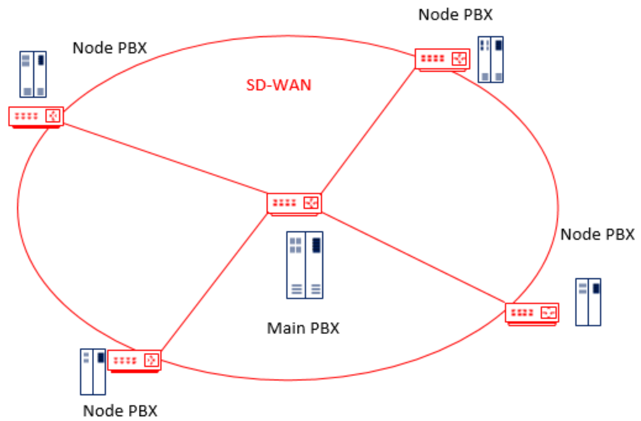

Fig.3. Third phase with SD-WAN

With the installation of SD-WAN technology, network will reach a point when all node VoIP PBX could be migrated from the classic relay technique to standard server systems. As can be assumed, the system could still function according to the old numbering plan, all communication between the centers would be done through new connections. Services that were isolated in their own networks can now be routed through separate VLANs/VRFs (Virtual Local Area Network/ Virtual Routing and Forwarding) and can also be isolated, i.e. function according to the old principle.

The following figure (Fig.4). shows a diagram of the possible connectivity of locations with all modes of transmission.

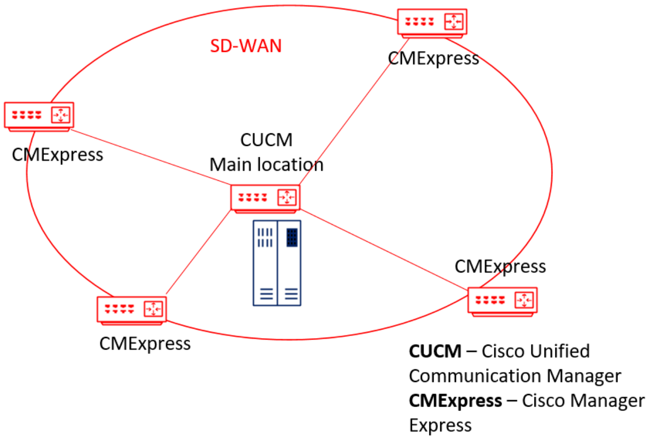

Fig.4. Network after all the phases.

So, VoIP solution should be done with:

- excessive assessment and planning – with detailed current system analysis, requirements gathering (sometimes managers are unaware of all possibilities), defining scope and objective, risk assessment
- design phase – prolonged because of the incomplete transmission network, architecture design (clustering, call routing policies, numbering plan...), and in some cases integration with existing systems using all possible interfaces (FXS/FXO Foreign Exchange Subscriber/Foreign Exchange Office)
- testing with proof of concept – test environment setup, interoperability testing, failover and pilot sites
- deployment – being in various forms as phased rollout (from edges to main location), coexistence and cutover
- monitoring, with various maintenance scenarios
- integration to overall disaster recovery plan for railway network
- integration, as much as possible, with specific railway systems (PA- Public Address, dispatching if regulations allow for this type of integration, technical protection systems...).
- excessive training and documentation (throughout the planning, implementation, deployment, testing and all following steps).

3. EXPECTED NETWORK CHARACTERISTICS

Introducing SD-WAN technology to all locations, which would have redundant links to the main VoIP location, space is opened for the partial abolition of the creation of a system where VoIP network will be done according to installation and commissioning dictated by the vendor (virtualization, clustering, active/active, active/passive…)[5]. This paper will use the well-defined principles for explanation of the possible solution based on Cisco Unified Communication Manager solution (CUCM). CUCM is a platform with multiple possibilities with one main function – call manager. On of the reduces variant is an CM Express being a solution for locations with small number of subscribers. Mentioned solutions for telephony networks are always including Survivable Remote Site Telephony as good variant if migration from legacy telephony is in focus.

All vendors have similar solutions, providing localized calls, mobility and conferencing. This specific vendor has it on ISR (Integrated Services Router) [5].

Node (lower level location) could thus be realized with a full or reduced solution. However, main location must be supported with full capabilities CUCM (Fig.4). Main locations are nowadays mainly virtualized, which is also used in case of CUCM. It runs on so called Cisco flavor of Linux.

Adding some additional equipment to CUCM could support Mobile and Remote Access (MRA) with firewall traversal solution [5].

Fig.5. [6] shows such solution.

One of the main disadvantages of such a system would be the maintenance. Maintenance personnel must be fully educated to work in computer networks as well as special training for VoIP systems. Another problem, which should not be ignored, would be the hardware of the VoIP system itself.

System hardware has a predictable and significantly determined lifetime. It should also be considered, that if migration is done, the virtualization and storage solutions must be supported in order to have the option of working in two locations at the same time.

Cloud-based solution could also add another dimension for clients (WebEx) [5].

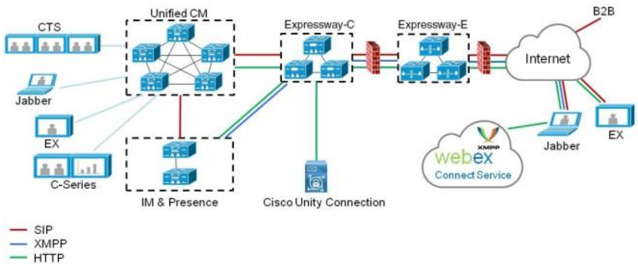

Fig.5. CUCM solution with Instant messaging and Presence, Expressway, WebEx, including various endpoints [6]

4. CONCLUSION

The collaboration solutions must enable all the standard communication services contemporary wok environment provides. This should be accompanied with railway specific services that could (according to regulations and possibilities) be integrated in such a network.

This VoIP based network must be realized in phases according to railway road plan. One of the first prerequisits of VoIP network is a fully functional transmission network. Most of the main lines are planned for such a outcome.

Presented solution could benefit from all vendor's additions to this particular system – IM&P, cloud solution (WebEx), Expressway, etc.

Collaboration solution discussed in paper is especially beneficial for nomadic employees in railway environment. Integration of VoIP solutions with existing network could group maintenance personnel, but will also increase the level of training and education needed for this personnel. This is the most controversial issue arising from this migration. Unified communication aspect is just addition on already vast pool of services.

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USING NEW TECHNOLOGIES TO IMPROVE MANAGEMENT CONTROL OF ELECTRICAL POWER PLANTS OF RAILWAYS OF THE REPUBLIC OF SRPSKA

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Abstract *– The paper will show the advantages of using a more technologically advanced and better software quality system of remote control of electric traction substation on the Railways of the Republic of Srpska, which replaced the old remote control system, and new methods of data collection were realized, a greater number of appropriate communication protocols in the operation of the system itself, reduced need for regular maintenance. Comparative values, the number of working hours on maintenance, and the advantages and disadvantages of both devices, for the reception and transmission of data in the remote control of electric traction substation compared to the former remote control system at the Railways of the Republic of Srpska, are shown in a table. The development of technology has expanded the requirements of the end user. , so the upgrade of the control devices and the new approach to the exploitation of the devices can be viewed through the prism of economic profitability and maximum utilization of the devices, as well as increased safety of railway traffic.*

Keywords – railways, maintenance, remote control, electric traction substation.

1. INTRODUCTION

The remote control center (CDU) of the electric power system of the Railways of the Republika Srpska serves to manage stable electric traction plants on the tracks Šamac - Doboj and Doboj - Banja Luka - Novi Grad. The CDU located in Doboj supervises and manages 6 EVP plants, 7 PS plants and 5 PSN plants located along 310 km of electrified railway, Figure 1. The primary task of the remote control center is to manage the associated power grid in order to ensure stable operation and maintain the integrity of the system. The primary task of the remote control center is to implement the management of the associated electric power network in order to ensure stable operation and maintain the integrity of the system. These tasks are achieved by the management and communication functions, that is, by the analytical functions implemented in the CDU. The management functions enable the operational staff to review the state of the EES, provide quick and complete information on all events in the process, and ensure the mechanisms by which the staff will intervene in the process. This presupposes the introduction of media for the presentation and manipulation of data. In addition to managing the process, operational staff should have insight into the state of the information system. Communication functions primarily involve data exchange with the process. It should ensure the accuracy of collected data and control signals, timely yield and protection mechanisms. Communication with the process is achieved through information equipment installed in substations (remote stations and local guidance systems). The working and technological life of the system configured for the needs of Railways of the Republic of Srpska has expired, which is why the maintenance costs have increased significantly. It is not possible to install a newer version of the software on existing hardware, for which spare parts are no longer produced. The existing configuration does not provide the possibilities offered by modern systems, such as:

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remote control of all system elements, more efficient and faster diagnostics, as well as data transfer through new communication protocols.

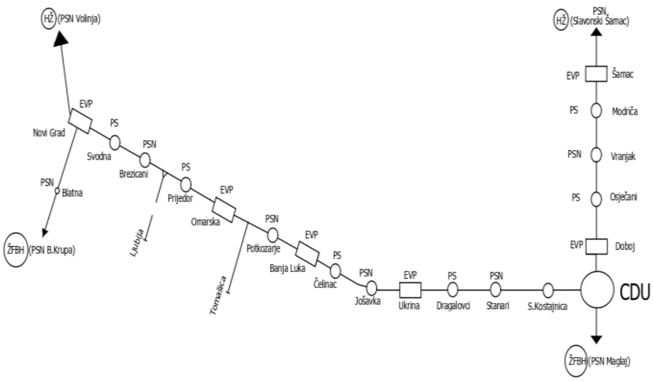

Fig. 1. Disposition of managed electric power plants on the Railways of the Republic of Srpske

2. ADVANTAGES OF THE MODERNIZATION OF THE DU SYSTEM ON RAILWAYS OF THE R.SRPSKE

At the Railways of the Republic of Srpska, a new DU system was installed, based on modern devices and appropriate software applications that use client-server communication. The configuration of the newly installed system consists of personal computers with associated communication equipment for connection with substations (EVP, PS and PSN). DU equipment in plants consists of remote stations. Local control in EVP, PS and PSN is realized through the control panel, while the remote control function is implemented through the remote terminal unit (RTU). At the Railways of the Republic of Srpska, a new DU system was installed, based on modern devices and appropriate software applications that use client-server communication. The configuration of the newly installed system consists of personal computers with associated communication equipment for connection with substations (EVP, PS and PSN). DU equipment in plants consists of remote stations. Local control in EVP, PS and PSN is realized through the control panel, while the remote control function is implemented through the remote terminal unit (RTU). A major drawback of the old system was the massive and complicated cabinets in power plants. This was overcome by the installation of modular devices (Figure 2) which, thanks to their technical characteristics, provide great opportunities for optimization, significantly reducing the number of elements of the system itself.

CDU equipment can be functionally divided into two parts:

- SCADA servers and workstations, i.e. computer nodes,
- computer network (network equipment) and communication equipment

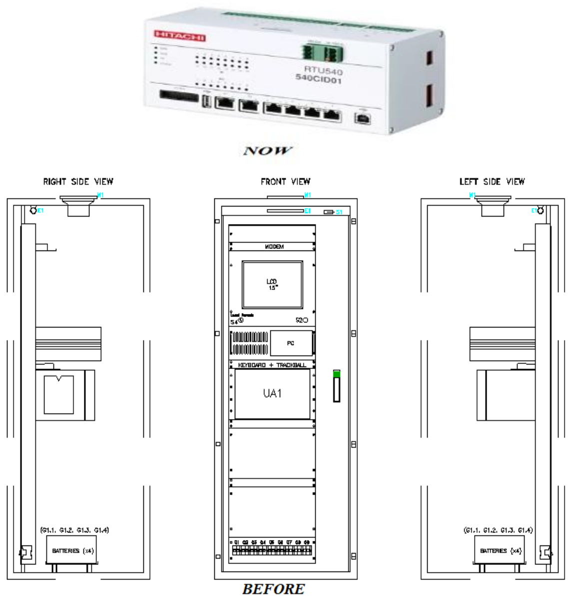

Fig. 2. The appearance of the old and new device

SCADA servers are industrial-grade personal computers made of high-quality components with high MTBF (mean time between failures). In the system, there are two server computers with identical basic configuration that function as dual computers.

A computer network is a system designed and implemented as a computer network with the Ethernet circuit standard and the TCP/IP communication protocol. In the network, no server computer has been defined for the computer network, but the workstations are peer-to-peer. Server computers are not network servers but only SCADA servers. The parts of the network configuration are:

- network cards in computer nodes
- cable network distribution - UTP cable
- network switch
- modems.

In computers, the network card is integrated on the motherboard. It is a network adapter with full duplex functions. The connection to the network is made with a cable with twisted pairs without a jacket over a UTP cable that enables simultaneous transmission and reception of data at a speed of 100 to 1000 MBps. The switch enables a star network configuration and enables full duplex transmission (as opposed to a coaxial cable configuration where network nodes are connected in a loop). The device is equipped with local signaling (LEDs):

- device in operation
- failure on the switch
- transmission error
- state of individual channels (workstations).

For the connection to monitored facilities (EVP, PS and PSN), modems with optical outputs for connection to the optical cable and modems for connection to the STKA cable are installed.

2.1. The advantage of simultaneous communication via copper and optical cable

In terms of transmission, the system is designed in master-slave communication between servers and remote control devices in power plants (master-slave communication with request - Request and direct response - Response) and adapted for communication via copper and optical transmission paths. While communication with the old system was realized exclusively through copper cables, the new system for the transmission of information and commands uses devices that allow the use of copper and optical cables. In this way, the previous modems were replaced, which ensured greater reliability of the system. Due to the deterioration of the copper cables, in the period before the installation of the new system, an increased number of interferences were recorded on the transmission path of the remote control system. A graphic representation of the number of disturbances (drive disturbances), by year, directly caused by the failure of integrated circuits in the power cabinet is shown in Figure 3 [1].

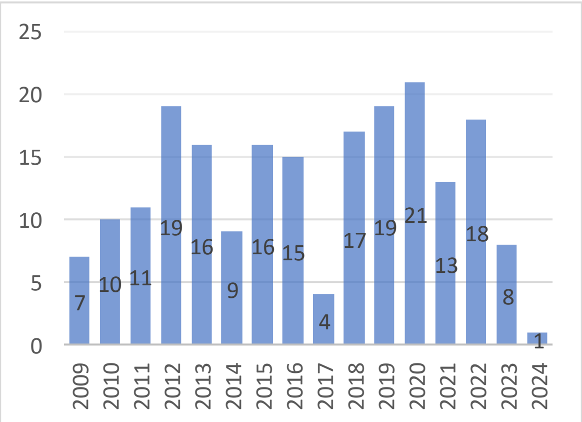

Fig. 3. Number of operating disturbances on the DU device from 2009 to IV 2024

2.2. Comparative capabilities of the new and old remote control system

By installing a new device for remote control, we managed to unify all the process actions of the centralized system and improve the work itself, as well as get the ability to upgrade power plants with digital devices for which the former system did not have the ability to support. The EE cabinet consists of a remote control device, modular units, 2 communication units for both transmission paths, multiple input/output boards, interface protection relays and devices for both types of power supply (DC/AC) in a metal DIN rail housing.

The key functions of the device are:

1. Receiving analog input signals (mA/V signals),
2. Receiving digital input signals,
3. Sending binary commands (with the help of a relay),
4. Management and control of input/output boards via serial port,
5. Loading process events from input units,
6. Printing commands to output units,
7. Communication with control centers and local networking systems by the man-machine system (MMI) through the integrated serial line interface and the applied Ethernet interface 10/100BaseT LAN,
8. Managing the time base for the remote control device and synchronizing the input and output panels,
9. Handling the dialog between the remote control device and the Web Browser via the LAN interface.

The two microprocessors represent the key parts of the control boards and have the following tasks:

- The MPU is a 32-bit main processing unit,
- SLC 8 bit serial line connector,
- I/O 8-bit input/output controller.

Tab. 1. Comparative capabilities of the two systems

SYSTEM CAPABILITIES	Old system	New system
Reception of 8 analog input signals	•	•
Reception of 16 digital input signals	•	•
Management of the input and output panels of the device via the serial port	•	•
Printing commands to output units	•	•
Loading preocess events from input units	•	•
Printing commands to output units	•	•
Management of the time base for the station i	•	•
Synchronization of input and output panels		•
Integration of multiple communication protocols		•
Functional system of work with copper and optical cables		•
The possibility of connecting to new digital devices		•
Connection via ethernet network		•
Dialog handling between device and web browser via LAN		•
Management of the time base for the station i		•

The SLC (Serial Line Controller) works as a master for the serial peripheral bus of the RTU. Single-pole and double-pole values are resolved in 4096 steps (12 bits + sign) for 100% of the measurement signal. Differential inputs are protected from static and dynamic overvoltages by protection circuits. A low-pass filter reduces non-linear AC interference. The AD converter working on the basis of the sigma/delta method has the possibility of scanning with a higher resolution and additional algorithms for reducing the line frequency and interference voltage of line harmonics. Even for a deviation from the line frequency of +/- 10% there is a reduction of >45dB. The internal high resolution enables scanning of all measurement ranges with the same resolution on the board. Table 1 shows the basic difference between the old DU device and the new DU device, table 1.

2.3. The cost of owning an EE plant

Knowing that every malfunction and interruption of communication causes the impossibility of controlling remote plants, the obligation of possession of the plant by the power plant maintenance staff is prescribed. Figure 4 shows the costs of owning the plant, expressed in the net wages of workers, for the duration of operating disturbances, caused by the wear and tear of the old remote control system. It should be noted that hiring workers for these needs simultaneously reduces the number of hours of regular maintenance of other power plants. [2].

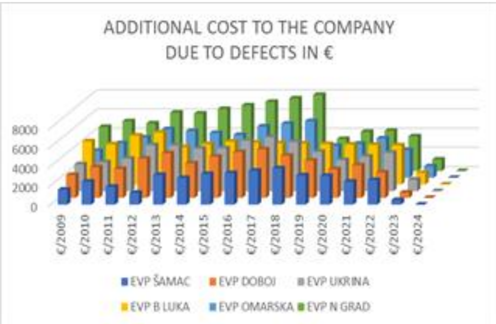

Fig. 4. Shown cost of owning an EVP plant expressed in euros

The advantage of the new system is a significantly lower number of hours of mandatory regular maintenance. Figure 5 shows a comparison of the required number of maintenance hours per month for the old and new remote control systems. The number of hours of maintenance is prescribed by the technical documentation of the equipment manufacturer and the Normative for ongoing maintenance of electro-technical devices and facilities of the Railways of the Republic of Srpska. [3].

Fig. 5. Number of maintenance hours old system/new system

3. CONCLUSION

Within the framework of the new remote control system, the possibility is left for possible circuit and functional expansions. Upgrading is possible in terms of expanding the monitored power system, adding new facilities and introducing new information. This enables the capacity of the program system, whose database can contain up to 100,000 pieces of information. Expanding the space for data archiving is simply done by increasing the number of disks (internal or external). The system allows expanding the configuration by adding new workstations, local or remote. Local workstations can be new operator sites, development sites, or maintenance service sites. The system is also open for program extensions. The necessary software support for data transfer is simply upgraded by installing computers with appropriate tools (data processing and presentation programs) on the network. The architecture of the software system enables the development and implementation of specific user applications, by the user or the system supplier. The system supplier has left the possibility of upgrading the system with functions that will be developed in the future. The designed remote control system is equipped with communication and software for communication with other control centers. The installation of the new system provides the possibility of using an optical cable for connection with remote facilities, which will significantly advance and improve the operation of the RS Railways power network management system. Savings were achieved on spare parts and less need for manpower to maintain the device. The biggest advantage is the reduced possibility of failure due to the simplicity of the design itself and the smaller number of elements compared to the complicated old system that used to manage power plants in the past.

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MONITORING AND OBJECT DETECTION ON RAILWAY VEHICLE UNDERCARRIAGES USING DEEP LEARNING

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Abstract *– The rapid advancements in deep learning technologies are transforming the way visual inspections are conducted in the railway industry. Traditional methods of monitoring railway vehicles by human inspector are both labor-intensive and costly. To address these challenges, this paper focuses on the application of deep learning, specifically convolutional neural network (CNN) for automated object detection undercarriages of railway vehicles in real-time. The integration artificial inteligence solutions into railway monitornig especialy for visual inspection of railway vehicles promises significant cost reductions, improved operational reliability, and enhanced safety standards. This paper also presents a case study demonstrating the effectiveness of CNN (YOLOv5) in detecting and identifying critical components in the undercarriage of railway vehicles, showcasing the potential of deep learning in the future of railway visual inspections.*

Keywords – visual inspection, deep learning, monitoring, railway, CNN.

1. INTRODUCTION

In recent years, the rapid evolution of application deep learning technologies has brought transformative changes to various industries [1, 2], including the railway sector, especially for railway track defects [3], obstacles on the tracks [4, 5] or railway vehicle [6, 7]. One area where these advancements are proving particularly valuable is in the domain of railway vehicle inspections . For example, with convolutional neural network it is possible to proven efficency of using resources and able to detect obstacle with high accurately [8]. Safety legislation mandates that all passenger and freight trains undergo regular inspections, with no national exceptions to this rule. As a result, all train engine owners must adhere to these requirements. Visual inspection in railways is the operation that is done by inspectors, who look directly at the parts to determine the operation condition of essential parts. Traditional visual inspection can be significantly improved by using deep learning [9].

This paper aims to explore and evaluate the application of advanced deep learning models, specifically, for automating the visual inspection in railway transport. A specific example of applying a convolutional neural network YOLOv5 for detecting critical components on the 441/444 locomotive is demonstrated using the RoboFlow software. This enables visual inspection through deep learning methods for the undercarriage of railway vehicles, enhancing the efficiency of maintenance and monitoring of all key components crucial for railway traffic safety.

2. CONVOLUTIONAL NEURAL NETWORK

YOLOv5 is an advanced real-time object detection model known for its speed and flexibility. It offers different model sizes as YOLOv5s, YOLOv5m, YOLOv5l, and YOLOv5 allowing users to balance with accuracy and performance. Its single-stage detection pipeline enables quick identification of multiple objects in a single pass, making it highly efficient for real-time applications like autonomous vehicles, drones, and video surveillance. Implemented in PyTorch, YOLOv5 offering easy customization and retraining for specific tasks. It uses anchor boxes to improve detection across various object sizes and

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shapes and applies advanced training techniques like Mosaic data augmentation for enhanced accuracy. YOLOv5 is widely used in industries requiring real-time, high-accuracy object detection.

3. MONITORING IN RAILWAY

Monitoring in the railway transport is a critical aspect of ensuring the safety, efficiency, and reliability of rail transport systems. It involves the continuous observation and assessment of various components, systems, and operations to detect potential issues before they escalate into failures.

Deep learning algorithm such as YOLOv5 offer a powerful solution for enhancing railway monitoring. YOLOv5 is capable of identifying and classifying objects in images in real time especially for the detection of moving objects. When applied to railway monitoring, YOLOv5 can automate the detection of defects or abnormalities in components like undercarriages, wheels, and brake systems, providing faster and more accurate results (Fig.1). This system enables operators to detect potential issues before they escalate into critical failures, significantly improving maintenance efficiency and safety. As part of service inspections of traction vehicles, according to the Rulebook on maintenance of railway vehicles, a visual inspection of the rolling stock, brake system, and other devices and assemblies is carried out.

As part of the visual control of the bogies, as part of the service inspection, it is necessary to carry out an inspection and pay attention to the following:

• Axle assemblies (see if there is damage/cracks on the axles (shaft), wheels, wheel rims, reducers, and if there are leaks from the reducers).

• Traction motors (see if there is any damage to the traction motor covers, reducer-traction motor coupling elements).

• Diagonal pole (see for damage to the diagonal pole, for the bolts and nuts of the diagonal pole; see for damage/cracks on the bogie frame brackets).

• Brake lever (see if there is any damage on the triangular rods, brake regulators, and brake lever-screw connections).

• Brake cylinders (see if there is any damage on the brake cylinders and on the connections of the piston and the brake lever).

In the continuation, we will focus on several components of the locomotive undercarriage, which will be described in detail in the next section.

4. DATASET

During the initial inspections, optimal positions for recording specific objects (Fig. 1) undercarriage railway locomotive were identified within the visual inspection of the undercarriage. Based on these defined positions and multiple repeated visual checks, over 1,000 images were collected. The dataset has total 295 images were selected that prominently feature essential components of the locomotive's undercarriage, which are necessary for training our proposed model for detection object with algoritham YOLOv5.

Divided into 5 distinct classes or labels (Fig.2), which are: class 1 (axle or shatf), class 2 (wear on the shaft) class 3 (flange), class 4 (reducer) and class 5 (wheel). These images were collected from real trucks, under controlled lighting conditions to reduce shadows and glare, ensuring that the details of potential defects could be easily distinguished. The images were captured using a GoPro Hero 8 camera. The original resolution of all images was 1920 x 1080. During preprocessing, the final resolution was adjusted to 640 x 640 (dimensions). To increase the number of images we used a data augmentation shown in the table 1.

Tab. 1. Data augmentation

Augmentation	Values
Flip	Horizontal
Crop	With 0% Minimum Zoom, 25% Maximum Zoom
Rotation	Between -15° and +15°
Grayscale	Apply to 15% of images
Brightness	Between -25% and +25%
Blur	Up to 2px
Exposure	Between -10% and +10%

The total number of images after data augmentation was 707, divided into three categories: the training set with 618 images (87%), the validation set with 59 images (8%), and the test set with 30 images (4%).

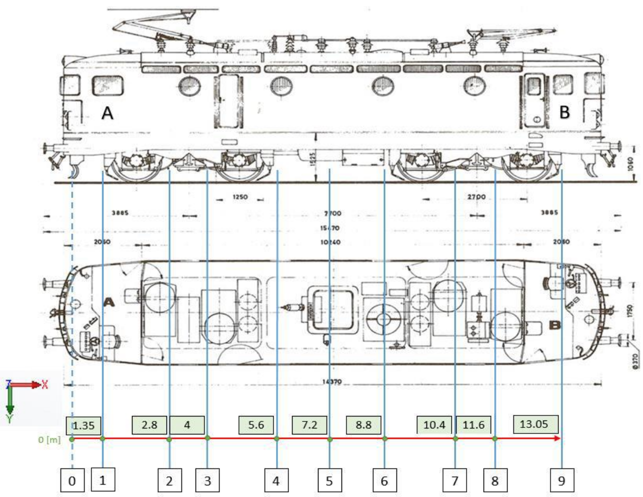

Fig.1. Images collected from positions and distances at undercarriage locomotive 441/444.

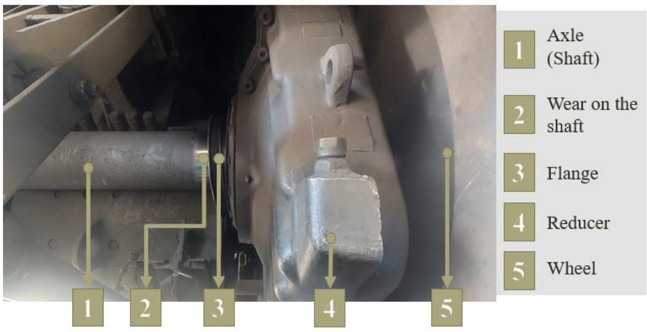

Fig.2. Objects on the locomotive 441/444 undercarriage for monitoring

5. IMAGE ANNOTATION

The total number of annotations is 863, with an average of 2.9 annotated objects per image across the 5 classes. The polygon tool was used for annotation, with the option to apply the smart polygon feature later (Fig. 4). The number of annotations per class is as follows: class 1 (Axle) has 289 annotations, class 2 (Wear on the Shaft) has 50, class 3 (Flange) has 57, class 4 (Reducer) has 215, and class 5 (Wheel) has 252.

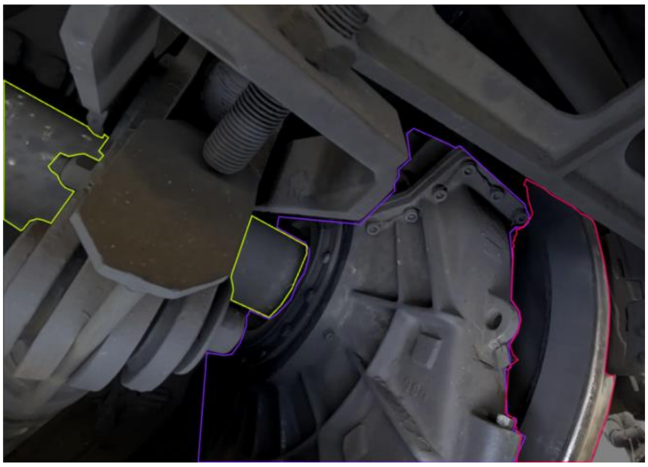

Fig.3. Annotation of a Axle (shaft), Reducer and Wheel using the Roboflow software

6. RESULTS AND DISCUSSION

We have calculated several metrics to evaluate the performance of our proposed model. These metrics offer valuable insights into various aspects of the model's ability to detect undercarriage components in railway images. The primary performance metrics used in our approach include precision, recall, and mean average precision (mAP).

Precision refers to the model's ability to accurately detect undercarriage components in a cluttered image, while minimizing the occurrence of false positive detections. The value of precision of our proposed model is 92.7%.

Recall refers to the model's ability to detect all instances of undercarriage components in a cluttered image. The value of recall of our proposed model is 91.7%.

mAP measures how well the model performs across various undercarriage components. It is calculated by averaging the precision-recall (PR) curve for each component. We used two types of mAP: mAP50 and mAP50–95. mAP50 is calculated by averaging precision at a fixed IoU threshold of 0.5, while mAP50–95 averages precision over a range of IoU thresholds from 0.5 to 0.95. A predicted bounding box is considered a true positive if its IoU with the ground truth bounding box exceeds a threshold, which in our case is 0.7. Both mAP50 and mAP50–95 provide a measure of the model's overall performance across different IoU thresholds, with a higher mAP indicating better performance. The value of mAP (Fig.4) of our proposed model is 92.4%.

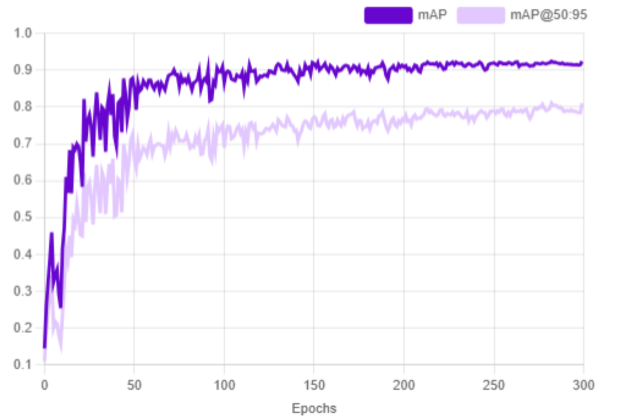

Fig.4. Mean average precision (mAP and mAP50–95) convergence curves

Additionally, to effectively support railway maintenance operations, it is essential not only to detect the presence of undercarriage components but also to identify missing parts or recognize defects. Our proposed model was tested to detect defects such as a displaced reducer flange and surface wear on the shaft. Based on 50 annotations, the model successfully identified shaft wear with 87% confidence (Figure 5).

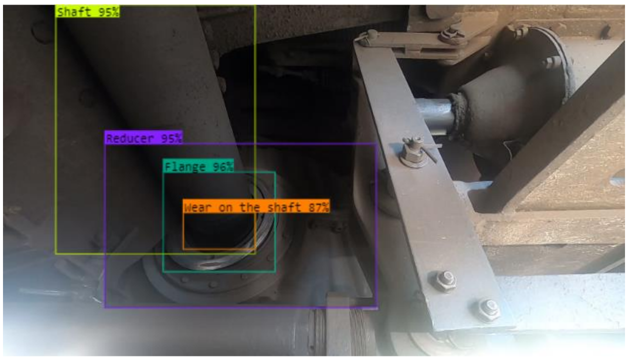

Fig.5. Defect: a displaced reducer flange and worn surface on the axle (shaft)

The training and validation curves are displayed in Fig. 6. It illustrates the performance of different learning curves plotted against the training epochs for both the training and validation datasets.

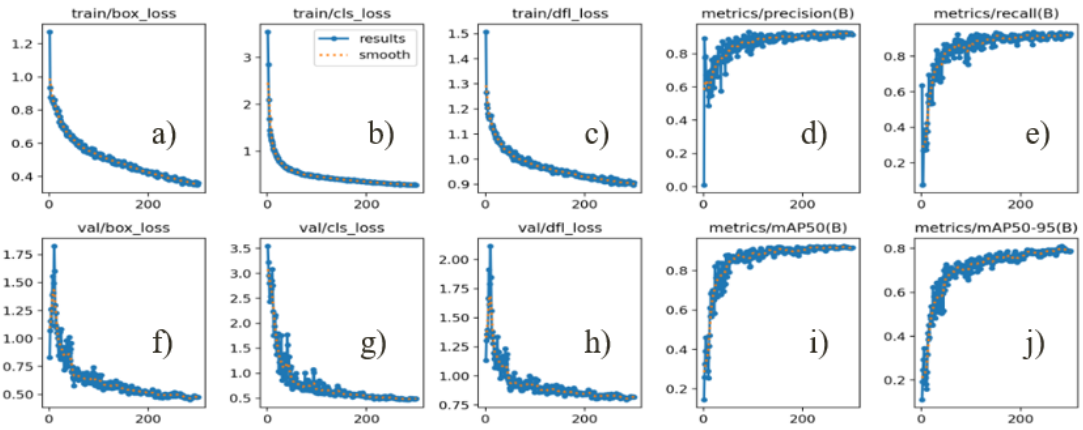

Fig. 6. The 1st row depicts the training curves for the (a) box loss, (b) classification loss, (c) DFL loss, (d) precision, and (e) recall. The 2nd row showing the validation curves for the (f) box loss, (g) classification loss, (h) DFL loss, (i) mAP50m and (j) mAP50–95.

7. CONCLUSION

This research article provides insight into the possibility of applying one of the deep learning algorithms for object detection, using a specific example in railway transport. It demonstrates that it is possible to apply this type of method in conditions where objects are not clearly visible and when they appear very similar, achieving high precision. It is possible to replace the traditional approach to visual inspection with artificial intelligence methods, particularly with deep learning algorithm. By increasing the number of images in the dataset, performing precise manual annotations, and applying the appropriate deep learning algorithm, we can significantly improve the results of object recognition on the locomotive undercarriage and achieve comprehensive visual inspection using deep learning models.

For future research its interesting to test the model and assess its accuracy under different conditions, such as nighttime, early morning, bright sunlight, and fog. The possibility of integrating cognitive positioning of visual inspection devices with object detection also presents an intriguing topic for further research.

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RAILWAY TRACK DEFORMATION RESULTING FROM A CURVE NEAR ONE LEVEL CROSSING

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Abstract *– Numerous deformations and failures occur to the railway superstructure within a period of its projected life of use. The rails are the most exposed part of the superstructure for wear. In addition to transferring the vertical load from the vehicle to other elements of the superstructure and substructure, the rail, being in direct contact with the wheel of the vehicle, is subject to several other static and dynamic effects during traffic. In the case of a predicted impact, some procedures can be implemented to minimize rail wear and extend their service life. However, unfavorable circumstances arise, quickly reducing the service life of rails and might contribute to more serious accidents. The investigation focuses on the specific phenomenon of rail's head deformation and track lateral movement at the point of the curvature, when the curvature was placed next to one level crossing. A collection of field data has been studied for a variety of curves. The findings of this study revealed assumption that position of the curvatures in respect to the one-level crossing disrupts the geometry of the track, resulting in rail deformation, is not entirely valid.*

Keywords – railway track deformation, rail in curvature, railway crossings.

1. INTRODUCTION

The friction between the wheels of the railway vehicles and the rails is what causes train to move onto the tracks. In this circumstance, the contact surfaces gradually and inevitably degrade. Railway vehicles have a characteristic shape of the wheel with a section that lies vertically on the rail (middle circle of wheeling) and an inside edge that guides the vehicle and ensures its lateral stability. The appearance of the characteristic wheel of the vehicle and the rail in the direction is presented in the Figure 1 [1]. Clearly, there is a gap between the inner surfaces of the rails and the edge ($\delta1+\delta2$) allowing fluid movement of the train. This gap varies during the train movement.

When the train passes through a curvature, the vehicle's position in relation to the rails changes. The weight is no longer uniformly transferred over both rails. Due to the appearance of centrifugal force in the curvature, the outer rail is elevated. The superelevation is determined using the design speed [1, 2]. If, for any reason, the train goes slower than the calculated speed the inner rail carries the majority of the train's weight and is heavily loaded on the side of the rail's head. In that case, the entire gap ($\delta1+\delta2$) is on the outer rail, while the wheel is pressed against the inner rail.

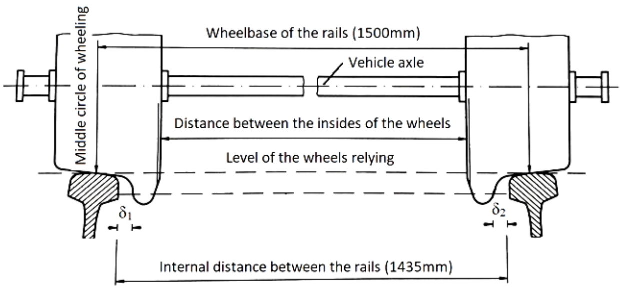

Fig.1. The appearance of vehicle and rail positions when the train is moving on a straight line [1]

If the train moves at the proper speed, the load is better distributed over both rails. It is troublesome when the train speed decreases, which frequently occurs when freight trains pass. It becomes much more challenging when there is a level crossing along the railway track in a curve and the train is obliged to stop or slow down for some reason.

The study gives data analysis on the deformation of track in a curvature caused by freight trains moving slowly. After two and a half years of operation, five one-level crossings were investigated for differences

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in outer rail superelevation in curvatures and internal distance between the rails.

2. MATERIALS AND METHODS

2.1. Study area

Research was carried out on the railway line number 219, Red Cross-Zaječar-Prahovo (km 0+000.00 ÷ 94+931.45), on the Matejevac-Knjaževac railway section from km 12+085,00 to km 69+000,00. The railway was designed for mixed traffic, but it is primarily freight traffic. This section of the railway underwent reconstruction between april 2019. year and december 2021. year.

Along with the deteriorating infrastructure, there was significant track deformation prior to reconstruction, including lateral movements toward the curve's center and crushing head of the rail on the inner rail. Frequent one level road crossings cause freight trains to run slower and sometimes even stop moving, which imposes a significant pressure on the inner rail and causes a part of the steel to be pushed out of the inner rail. This is a plastic deformation of rail, which is in jargon called a "nail" (Figure 2).

Fig. 2. Deformation of the rail’s head (condition before reconstruction of superstructure)

In the long term, this type of plastic deformation can significantly reduce the profile of head of the rail which is crucial information in terms of maintenance [3]. One of the causes of train derailment is the rail's profile reducing.

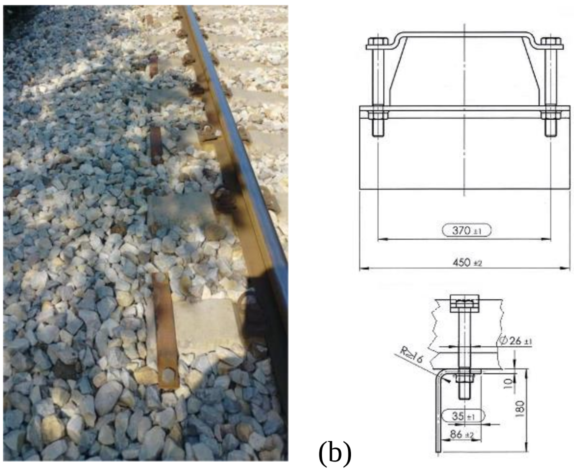
2.2. Techniques and procedures for track’s condition monitoring

Visual inspection and reporting of visual observations precedes instrumental assessment of the condition and position of superstructure elements. The internal distance between the rails and the superelevation of the outer rail were verified using the "Geismar" track management gauge (Figure 3).

Fig. 3. "Geismar" track management gauge

3. TRACK’S CONDITION AND CONSTRUCTION ELEMENTS AFTER RECONSTRUCTION

Railway reconstruction was finished in december 2021. The railway's renovation involved the replacement of superstructure elements such as ballast, sleepers, fasteners and rails. All elements match the applicable criteria [2]. Concrete sleepers B-70 and rail UIC 49 have been installed. The rails were attached to the sleepers with the skl-14 fasteners. It was foreseen to install devices to prevent lateral movement of rails [1] (Figure 4). The frequency of devices used to restrict lateral movement of the track is determined by the radius of curvature. According to the Regulations [2], devices are installed on every other sleeper within a curvature with radius of 250 to 400 m. In the case of curvature with a radius of less than 250 m, devices have been fixed on each sleeper.



(a) (b)

Fig. 4. Concrete sleeper's devices against lateral movement of the tracks: (a)-appearance of the devices on the track, (b)-device’s workshop detail (DIV-Svrljig)

Taking into account all of the factors that contribute to the disruption of the railway's stability and designed condition, as well as the experiences prior to the reconstruction, the section from Matejevac railway station (12+085) to Gramada station (30+000) was especially processed. This section of the railway has a slope of 8 ÷ 12 ‰, which not only decreases train speed but also negatively affects freight train traction.

This section's estimated speed is 65 km/h. Table 1 lists the basic geometrical characteristics of the major curvature points (transition curve beginning, curvature beginning, curvature ending, and transition curve ending) for curvatures 30, 32, 43 and 45, on the Matejevac-Gramada section. The situation after the reconstruction is indicated in these statistics. One level crossings are positioned at 19+393.37 (Crossing 1), 19+862.38 (Crossing 2), 20+043.18 (Crossing 3), 24+762.66 (Crossing 4) and 26+263.08 (Crossing 5).

Tab. 1. Position of curvatures numbered 30, 32, 43 and 45 on the railway line Red Cross-Zaječar-Prahovo

No	30	32	43	45
TCB	19+342.26	19+802.82	24+552.45	25+732.22
CB	19+412.26	19+882.82	24+632.45	25+792.22
CE	19+530.08	20+022.41	25+220.64	26+354.06
TCE	19+600.08	20+102.41	25+220.64	26+414.06
R	250	250	252	250
L	70	80	80/0	59
h	120	120	120	120

No- number of curvature on the railway line Red Cross-Zaječar-Prahovo
TCB- transition curve beginning
CB- curvature beginning
CE- curvature ending
TCE- transition curve ending
R- radius of the curvature
L- length of the transition curve
h- outer rail elevation (superelevation)

According to the data from Table 1, road crossings 1, 2 and 3 are located at the transition curves. Crossings 4 and 5 are situated on circular part of the curvature. Based on the given superelevations and the lengths of transition curves, the projected superelevations (h [mm]) of road crossings for crossings 1, 2 and 3 were determined. At crossings 4 and 5, the superelevations at the road crossings are the same as the maximum superelevation at the point of the curvatures number 43 and number 45 (Table 2).

Tab. 2. Outer rail's elevation for one-level crossings

Number of road-crossing	1	2	3	4	5
h [mm]	88	89	89	120	120

4. RESULTS AND DISCUSSION

The control was carried out after two and a half years of the exploitation period. Initially, the tracks in the observed segment were visually inspected.

The typical wear and tear of the driving surface at the curvatures was readily apparent. With the rails on the inside of the curvature, it was clear that the vehicle's wheel goes across practically the whole upper surface of the rail's head. In the case of outer rail, the vehicle's wheel also made a mark but only halfway to the railhead. A typical example of this phenomena is shown in the Figure 5.

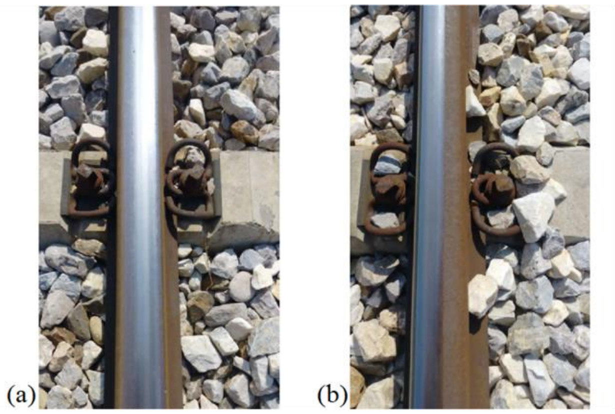


Fig. 5. Appearance of the rail's rolling surface following 2,6 years of exploitation: (a)-left inner rail, (b)-right outer rail

Another sort of deformation on the rails was identified as a wavy imprint on the rail. Given that the deformation occurs in the direction rather than the curvatures, it was determined that the trains have difficult traction. In this aspect, the locomotive's inadequate traction qualities for the specified slope of the track might cause the train to move at lower speeds than intended.

Fig. 5. Rail distortion caused by struggling train traction.

Aside from visual inspection, the internal distance between the rails and the outer rail elevation were verified using the "Geismar" track management gauge. During the inspection of the rail's internal distance, a continuous expansion of 4 mm was detected at the locations of all curvatures. The measurements also included one-level crossings.

The examination's findings reveal that the elevation of the outer rail at one-level crossings has increased significantly. Table 3 shows the precise results of the testing. In addition to examinations at crossings, superelevations were measured at random position in curvatures. The elevation differences between estimated and measured values were determined to be 15-20mm.

Tab. 2. Elevation of outer rail at the point of one level crossings

No	Position of the crossing	Year	Outer rail elevation h [mm]
1	19+393.37	2021	88
		2024	100
2	19+862.38	2021	89
		2024	110
3	20+043.18	2021	89
		2024	110
4	24+762.66	2021	120
		2024	140
5	26+263.08	2021	120
		2024	135

In the zone of one-level crossings, 2 m before and after it, a movement of the tracks in the direction towards the inner side of the curvature was observed. By measuring, it was confirmed that the elevation at those positions is non-linearly increased in relation to the track on very beginning or end of the one-level crossing, regarding the track at the transition curve. In the case of one-level crossing, in a position of circle curve, comparing the superelevation just before and after the crossing with the superelevation at the crossing, it is observed that the superelevations outside the crossing are greater. This leads to the conclusion that the level crossing improves the lateral stability of the track to a certain extent.

5. CONCLUSION

The condition of the track reconstructed two and a half years ago was examined. The research focuses on one-level crossings, specifically the internal rail gap and the rail's superelevation. A visual check and measurement revealed that, despite the recent repair, there was an obvious increase in track overhang of 15-20mm. Measured values exceed the desinged by 13.5-23.5%. In addition to the mechanism for lateral movement of the tracks, the internal distance increased by 4 mm along all curvatures. Another sort of rail distortion was discovered, indicating that the trains had problematic traction.

This invalidates a belief that the presence of railroad crossings is only responsible for the increase in overhang. It is evident that the train is not operating at the intended speed because of traction characteristics, not just one-level crossings. The measured data are concerning given the brief time of exploitation. If the replacement of traction vehicles is not addressed, maintenance costs might be substantial, making rail transportation unprofitable.

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EFFECTS OF SURFACE PREPARATION ON THE ADHESIVE BONDING OF ALUMINIUM ALLOY EN AW 5754 IN THE RAILWAY INDUSTRY

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Abstract *– In the railway industry, adhesive bonding is increasingly used as a reliable alternative to traditional mechanical fastening methods. This study investigates the effect of surface preparation methods on the bond strength of aluminium alloy EN AW 5754 using two different epoxy adhesives: SikaPower®-492 G and SikaPower®-880. To evaluate the performance of the bonded joints, single-lap shear tests were performed using surface preparation with Scotch-Brite abrasive pads and P180 sandpaper. The results showed that SikaPower®-492 G achieved higher bond strength with increased surface roughness, while SikaPower®-880 performed better on smoother surfaces, indicating that its formulation is optimised for better wetting and adhesion. These results provide valuable insights into the optimisation of adhesive performance as a function of surface conditions.*

Keywords – adhesive bonding, railway industry, aluminium alloy EN AW 5754, surface preparation, epoxy adhesives.

1. INTRODUCTION

Railways have advanced with three key objectives: high speed, safety, and mass transportation. Rolling stock, which refers to railcars in a broad sense, is the most energy-efficient mode of transport, using the least energy per person-distance compared to all other systems. In recent years, high speed, passenger comfort, safety, and environmental sustainability have become essential requirements for railway systems. These priorities emphasize the need for weight reduction, high strength, rigidity, noise insulation, vibration damping, thermal insulation, fire resistance, and recyclability [1,2]. Additionally, with the shorter service life and model-change intervals of railcars, cost reduction has also become a crucial factor. To address these diverse demands, the introduction of lightweight structures made from aluminium extrusions offers an effective solution. Adhesive bonding is considered the most promising method for joining these material structures in trains.

The use of adhesives for joining materials in modern rail vehicles is growing, particularly in applications like interior panels, floor plates, and coverings [2]. Adhesives offer several advantages over welding, including a high strength-to-weight ratio, better stress distribution, and greater design flexibility [3]. They also provide improved resistance to damage, fatigue, and crash impacts. Additionally, adhesives help prevent water from getting into the joints, reducing the risk of corrosion. Overall, adhesive bonding offers a more durable, versatile, and low-maintenance alternative to traditional welding [4].

Despite significant advancements in adhesive technology, several factors continue to limit the optimal design and reliability of adhesive joints. These include joint geometry, the type of adhesive used, and stresses caused by differences in thermal expansion between materials. A considerable amount of research has been conducted to analyze the performance of adhesive bonded joints, as reflected in numerous review papers [5-7].

One of the most important factors influencing the mechanical performance of bonded joints is surface

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preparation. When bonding aluminium it is essential to remove the oxide layer (Al_2O3), impurities and grease from the surface to ensure proper adhesion [8]. It is therefore important to carry out adequate surface preparation of the parts to be joined before bonding. The surface preparation of materials involves a series of steps to optimize the quality of the bonding surface in terms of adhesion and cleanliness. Depending on the material and the desired durability of the bond, various methods can be used. These methods include mechanical, chemical and electrochemical treatments, laser technologies and thermal techniques such as plasma or flame cleaning.

In the context of surface preparation to enhance bonding properties, numerous studies [9-11] have advocated for the use of mechanical removal techniques prior to bonding in order to eliminate contaminants and introduce geometric patterns on the bonding surfaces. Researchers such as Łyczkowska [12] and da Silva et al. [13] have specifically examined the preparation of aluminium alloys for adhesive bonding. Their findings indicate that sanding plays a critical role in the bonding process, as increasing surface roughness enhances the adhesive-to-substrate contact, thereby improving the joint’s shear strength. Sanding with various grit sizes of sandpaper is a commonly used technique due to its cost-efficiency, minimal training requirements, and lower expense compared to other surface preparation methods, making it particularly advantageous in large-scale production environments.

Based on the review of the current state of the art, this study focuses on analysing how different surface preparation methods for aluminium alloy EN AW 5754 affect the strength of adhesive bonds. The contribution of this study is to evaluate the effect of two different adhesives and surface preparation methods on the shear strength of bonded joints, providing insights into optimising adhesive bonding performance by analysing variations in surface roughness.

2. EXPERIMENTAL WORK

Aluminium alloy EN AW 5754 was used for the study, which is known for its favourable strength-to-weight ratio, excellent ductility and machinability, and remarkable resistance to corrosion and thermal effects, making it suitable for industrial railway applications. Detailed mechanical properties of the aluminium alloy EN AW 5754 are provided in Table 1 [14].

Aluminium substrates, each 2 mm thick, were bonded using a standardised geometry and dimensions, including an overlap of 12.5 mm, as depicted in Figure 1, following the EN 1465 standard [15].

Tab. 1. Mechanical properties of EN AW 5754 [14]

Yield Strength (MPa)	**Tensile Strength (MPa)**	**Elongation to Break (%)**	**Module of Elasticity (GPa)**
180	236	16.5	70

The surface preparation involved a mechanical abrasive process, where the surfaces were hand sanded and then cleaned with SIKA Remover-208, a solvent-based cleaning agent recommended by Sika Ltd. The sanding was performed using green, fine-grained Scotch-Brite pads and 180-grit sandpaper. The adhesive layer was 0.3 mm thick, with the thickness controlled by the glass beads embedded within the adhesive.

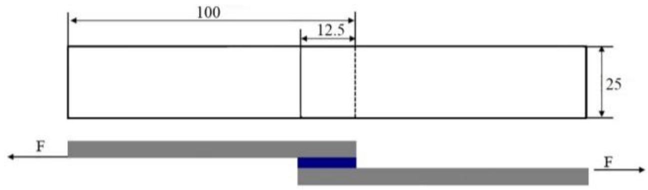

Fig.1. Dimensions of the aluminium substrates for the single-lap shear test [15]

This study considered the use of two different epoxy adhesives for investigation: the one-component (1C) epoxy hybrid adhesive SikaPower®-492 G [16] and the two-component (2C) epoxy adhesive SikaPower®-880 [17]. The main reasons for selecting these two adhesives were their availability and ease of use in the laboratory chosen for this study. They were also suitable candidates for this study due to their widespread use in the industry and their consistent performance.

The choice of surface preparation and adhesive bonding properties should aim to ensure that the weakest point in a bonded joint is within the adhesive layer itself, rather than at the interface between the bonded parts. Cohesive failure, which occurs within the adhesive layer, is the ideal failure mode as it best reflects the optimal performance of the bonded joints. The primary types of failure modes are illustrated in Fig. 2.

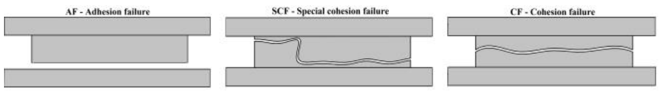

Fig.2. Failure modes of adhesive bonded joints: Adhesion Failure (AF), Special Cohesion Failure (SCF), Cohesion Failure (CF) [18]

All single-lap shear tests were performed using a 250 kN INSTRON 8802 universal testing machine at a crosshead speed of 1 mm/min, following the ISO 4587 standard [19]. To ensure repeatability, environmental temperature and humidity were strictly controlled, and three repeat samples were tested for each bonding scenario, with loads and extensions recorded by the machine.

The roughness of the aluminium alloy after both surface preparation methods was measured using a Mitutoyo SJ-301 profilometer, with the results reported as the average Ra and Rz values.

3. RESULTS AND DISCUSSION

The surface roughness of the samples prepared with Scotch-Brite abrasive pads and P180 sandpaper was measured longitudinally along 10 mm of the sample ends at a speed of 0.15 mm/s on all surfaces examined. The measurement results of two surface roughness parameters, Ra and Rz, in relation to the different surface preparations are shown in Fig. 3.

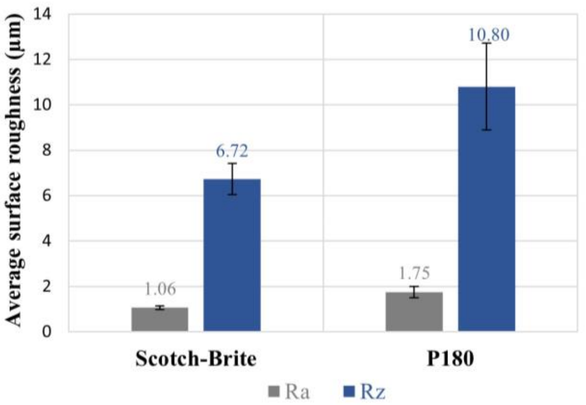

Fig.3. Average surface roughness of aluminium alloy EN AW 5754 depending on the surface preparation

After preparation with Scotch-Brite, the samples exhibited lower surface roughness, with average Ra and Rz values of ± 1.02 μm (ranging from 0.9 to 1.12 μm) and ± 6.64 μm (ranging from 5.94 to 7.54 μm), respectively. In contrast, aluminium alloy surfaces prepared with P180 sandpaper showed higher roughness, with average Ra and Rz values of ± 1.69 μm (ranging from 1.46 to 1.91 μm) and ± 10.49 μm (ranging from 8.65 to 12.33 μm), respectively.

The results of the static tensile shear test of the single-lap bonded aluminium joints in relation to two different surface preparations and adhesive types are shown in the form of a graph in Fig. 4.

The aluminium samples bonded with SikaPower®-492 G exhibited higher strength. The results suggest that surface roughness prior to bonding significantly influences bond strength, as preparation using P180 sandpaper showed slightly better results. The better strength results in the sample with higher roughness can be attributed to the increased surface area available for the adhesive to bond to, which enhances mechanical interlocking and improves overall adhesion.

Adhesive SikaPower®-880 demonstrates that surface preparation using Scotch-Brite leads to better strength outcomes. This suggests that SikaPower®-880 is more suited for smoother surfaces, where its formulation allows for improved wetting and adhesion, resulting in a stronger bond even with lower surface roughness.

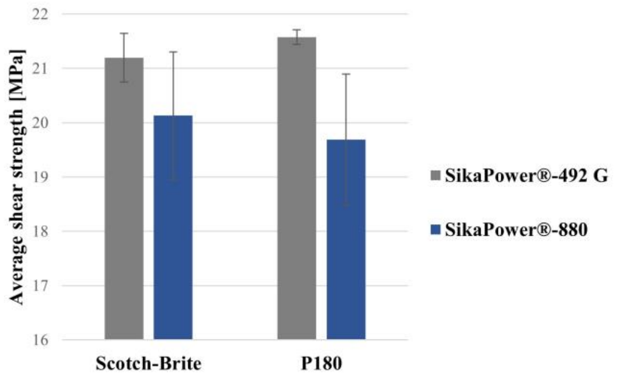

Fig.4. Average shear strength of bonded joints in relation to the method of surface preparation for aluminium alloy EN AW 5754

Fig. 5 and Fig. 6 show examples of fractures in bonded joints made with the SikaPower®-492 G and SikaPower®-880 adhesive.

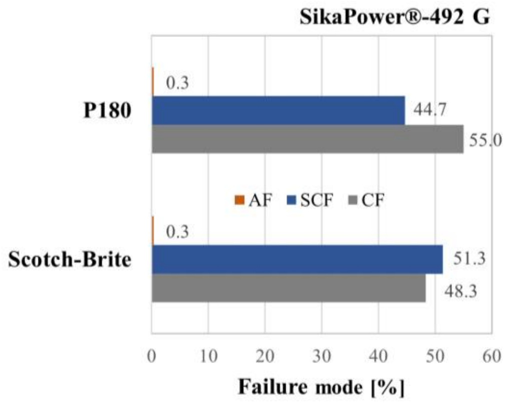

Fig.5. SikaPower®-492 G, AF - Adhesion failure; SCF - Special cohesion failure; CF - Cohesion failure

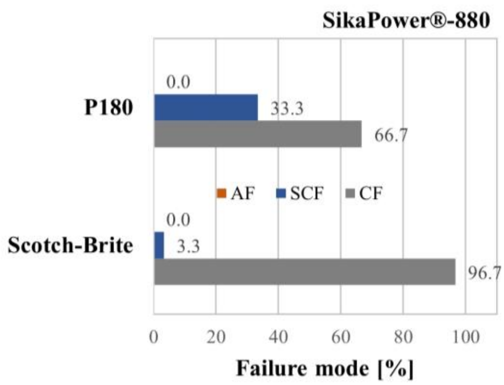

Fig.6. SikaPower®-880, AF - Adhesion failure; SCF - Special cohesion failure; CF - Cohesion failure

Adhesive SikaPower®-492 G exhibited adhesion failure in a small percentage of cases across both preparation methods, yet overall provided consistent results, predominantly showing cohesive or special cohesive failure. Notably, surface preparation with P180 sandpaper led to a greater occurrence of cohesive failure, correlating with higher measured bond strength.

Adhesive SikaPower®-880 demonstrated a dominant cohesive failure mode after surface preparation with Scotch-Brite, with 96.7% of failures occurring cohesively, which was further supported by the corresponding strength data.

4. CONCLUSION

The adhesive bonding of aluminium alloys in railway vehicles plays a crucial role in enhancing durability, reducing weight, and improving the overall efficiency and safety of modern rail systems. In this study, the effect of two surface preparation methods (hand sanding with Scotch-Brite and P180 sandpaper) on the single-lap shear strength of aluminium alloy EN AW 5754 using two different epoxy adhesives, SikaPower®-492 G and SikaPower®-880, was investigated. SikaPower®-492 G adhesive showed better bond strength with increasing surface roughness, suggesting that its adhesive properties benefit from a rougher surface that improves mechanical interlocking. In contrast, SikaPower®-880 performed better on smoother surfaces, with Scotch-Brite preparation giving better results compared to P180 sandpaper. This suggests that SikaPower®-880 is more sensitive to the wetting and adhesion properties of the surface, showing stronger bonds even at lower surface roughness. These findings emphasize the importance of selecting the appropriate adhesive and surface preparation method based on the specific application and material conditions.

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WELDING TECHNIQUES TRAM RAIL 54G2 OF R260 AND BLOCK OF COGIDUR USING FCAW-S PROCESS AND FATIGUE TESTING OF WELDED JOINT

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Abstract *– This paper explores the welding technology used for joining tram-rail 54G2 (1.0623 Group ISO/TR 15608-11.3.) with a block of Cogidur (1.8715 Group ISO/TR 15608-3.2) using a self-shielded flux-cored wire in a butt welding process, supplemented by copper washers. The study includes a comprehensive analysis of the welded joint, NDT testing as visual testing (VT) and penetrant testing (PT), as well as macrostructure and hardness evaluations. Furthermore, the paper details the final fatigue testing of the welded specimen, conducted at the Technology Center in Reichshoffen, France. The results of fatigue testing offer valuable insights into the structural integrity of welded joints done advanced welding techniques in rail systems.*

Keywords – tram rails 54G2/R260, block of crossings/cogidur, FCAW-S process, fatigue testing.

1. INTRODUCTION

Vossloh Laeis, a manufacturer of railway points, makes use of a material known as "Cogidur" for the purpose of lengthening the service life of points. Cogidur is a material that is harder than the steel normally used for rails. Moreover, it lends itself to welding even at low preheating temperatures.

The welding processes used to connect 54G2 (EN 14811)/R260 tram rails to the Cogidura block for switches and crossings are as follows: Aluminothermic welding (AT), Electric resistance welding (ET) and Flux-cored arc welding (FCAW). Electric resistance welding of rails (ET) is most commonly used in workshops, although mobile equipment for field welding is also available today. However, aluminothermic welding (AT) is currently the most widely used method for rail welding, both in workshops and in the field. Since 1996, flux-cored arc welding (FCAW) has been employed for rail joining. This process was developed by Lincoln Smitweld GmbH and received approval from Deutsche Bahn AG for welding rails and turnouts with tensile strengths ranging from R_m=685 MPa to R_m =885 MPa, for tracks with axle loads up to 10 tons and speeds below 80 km/h.

FCAW is a welding process that utilizes a flux-cored wire and generally employs similar equipment to the MAG process, but without the use of shielding gas. The welding characteristics are comparable to those of the E process (Fig. 1).

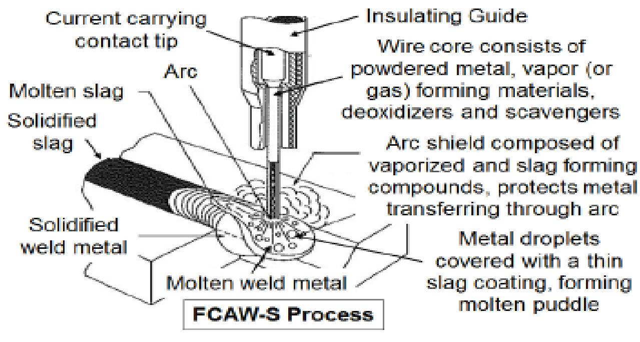

Fig. 1. FCAW-S self-shielding wire welding procedure

The flux-cored electrode wire can be considered a continuous electrode with a protective material inside a steel sheath, enabling a constant electrical contact between the wire and the copper contact tube in the

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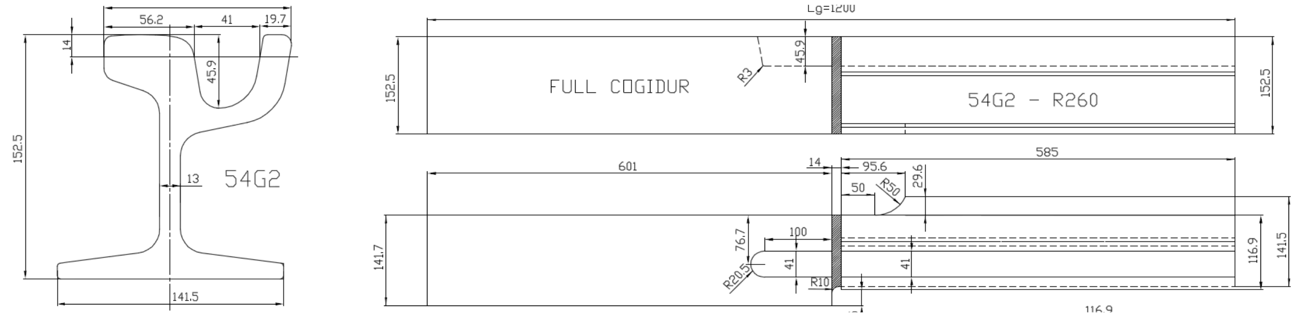
welding gun. This allows for significantly higher current values than those achieved with the MAG or E processes, resulting in higher productivity when welding or surfacing thicker materials. The diameters of flux-cored wires range from 0.9 to 3.2 mm.

2. EXPERIMENT

2.1. Base material

During the production of tram turnouts, it is necessary to weld the 54G2 rail (SRPS EN 14811) (Fig. 2a) - material R260 (Wr.Nr. 1.0623) to a steel known as Cogidur (17MnCr5-3; Wr.Nr. 1.8715) (Fig. 2b). Cogidur is a material that is harder than steel normally used for rails and it is normally used to extend the design life of rails. Moreover, it lends itself to welding even at low preheating temperatures. The crucial advantage of this material resides in the combination of its high wear resistance and its good weldability. Chemical composition of base material of rail 54G2 and material of Cogidur is given in the table 1, and mechanical properties in table 2. The welding was carried out at the "Vossloh MIN Skretnice" factory in Niš.



a) b)

Fig. 2. Cross section of tram rail 54G2 (a); preparation of the joint of the rail and the welding block (b)

Tab. 1. Chemical composition of base material- Mass Fraction in Percent (%)

Base material	C	Mn	Si	Ni	Cr	Mo	Ti	V	Cu
R260	0.62-0.8	0,7-1.2	0.15-0,58						
Cogidur	0.152-0,25	1.305	0.383	0.418	1.653	0.174	0.005	0.002	0.239

Tab. 2. Mechanical properties of base material

Base material	R_m MPa	$R_{p0,2}$ MPa	A %	Tvrdoća HB
R260	933-947	493-510	12.5-14.4	275 - 284
Cogidur	1355	1005	13	388-401

2.2. Filler material for welding and surfacing the tram rail-block joint

For welding the rail-block joint using the FCAW-S process, a self-shielded wire EN ISO 17632-A T 46 Z V N3, commercially known as Innershield NS-3M, manufactured by Lincoln Electric USA, with a wire diameter of Ø 2.0mm is used.

For surfacing using the FCAW-S process, a self-shielded wire EN14700 T Fe 1, commercially known as Lincore 33, also manufactured by Lincoln Electric USA, with a wire diameter of Ø 2.0mm is used. Chemical composition and mechanical properties of filler material are shown in Tab. 3 and Tab. 4.

Tab. 3. Chemical composition of filler material in %

Filler material	C	Mn	Si	P	S	Al	Cr
NS-3M	0,23	0,45	0,25	0,006	0,006	1,4	
Lincore 33	0,15	2,0	0,7			1,6	2,0

Tab. 4. Mechanical properties of filler material

Filler material	R_m MPa	R_e MPa	A %	Rockwell Hardness (RC)	
NS - 3M	640	470	27	No. of Layers	
Lincore 33				1	28-34
				2	32-36
				3	35-38

2.3. Welding process

The welding of the rail to the block is achieved by positioning them with a gap of 14-17mm between them, depending on whether the distance is measured at the base of the rail or at the top of the rail head. The edges of the rail and the block are ground to a metallic shine, and after checking the centricity of the block relative to the rail, a clamp is applied to hold them at the correct distance. After that, copper shims are placed on the sides of the rail in the base area, and a copper shim with a groove is already positioned underneath the rail and the block (Fig 3).

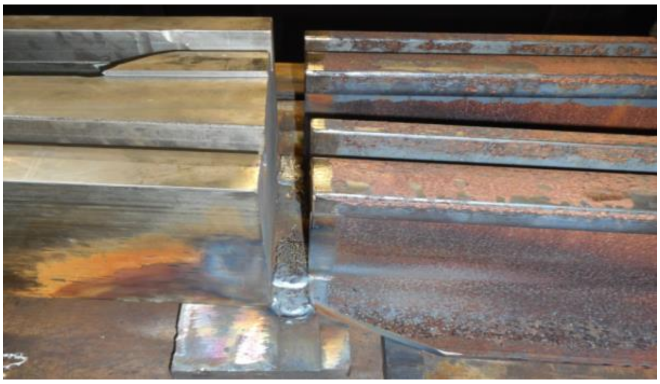


Fig. 3. Preparation for welding the rail base, 3rd pass

Before welding, the rail and block are preheated with propane-butane over a length of 500mm on both sides of the joint, ensuring that the material is heated through the depth of the block. The preheating temperature can reach up to 350°C for the rail and 250°C for the block, which is challenging to achieve in practice. After preheating, the base of the rail is welded to the block in two passes, and after these passes are completed, the copper shims are removed, and an additional pass is welded.

After the copper shims are placed, preheating is repeated due to the heat loss and cooling of the material. Placing the shims on a previously heated joint is challenging and requires the skill of the welder. By measuring the temperature of the rail and block material, and if it does not deviate by more than 10% from the value specified in the WPS sheet, the welding process continues using the FCAW method, continuously welding the neck of the rail to the block until the weld reaches the end of the rail neck. At that point, the copper shims are removed, and the weld is cleaned of slag using a pneumatic tool with vibrating wires. Afterward, at least three more passes are welded, leaving the last 30mm of the rail head unwelded. This is done because the final 30mm is surfaced with a self-shielded wire with a hardness of 33HRC. Throughout the welding process, the current values are closely monitored, ensuring minimal deviation from the values specified in the WPS sheet.

The welding parameters, as specified in the WPS sheet, show current values ranging from 290 to 350 A, depending on whether the base or neck of the rail is being welded. The welding voltage is between 29-31 V, the welding speed varies from 30 to 42 cm/min, and the heat input ranges from 1.2 to 2 KJ/mm.

For surfacing, the parameters are I = 280 A, U=30V, v = 28-30 cm/min, and E = 1.5-1.65 KJ/mm.

After welding the rail-block joint using the FCAW-S process, the joint is reheated to a temperature of 200°C for a duration of 1 hour. After that, it is covered with a fireproof blanket and allowed to cool slowly.

3. EXAMINATION AND RESULTS

3.1. Non-destructive testing

After 24 hours, a visual and dimensional inspection was carried out, examining both the welded joint itself as well as the parallelism of the rail and block, and checking for any possible deformation or shrinkage. Following this, penetrant testing and ultrasonic testing of the welded joint were performed (Fig 4). The critical point of the welded joint is at the end of the rail neck, where the welding stops, the copper shims are removed, and after cleaning and reheating, welding continues. At this stage, defects such as overlaps or non-metallic inclusions may occur.

Fig. 4. Welded rail-block joint

3.2. Destructive testing

Since the results of non-destructive testing were satisfactory, destructive testing was initiated, including macrographic examination and hardness testing (Fig 5). The testing was conducted by the laboratory "RD Dijagnostika d.o.o." in Belgrade, which is authorized by TÙV Thùringen Cert.

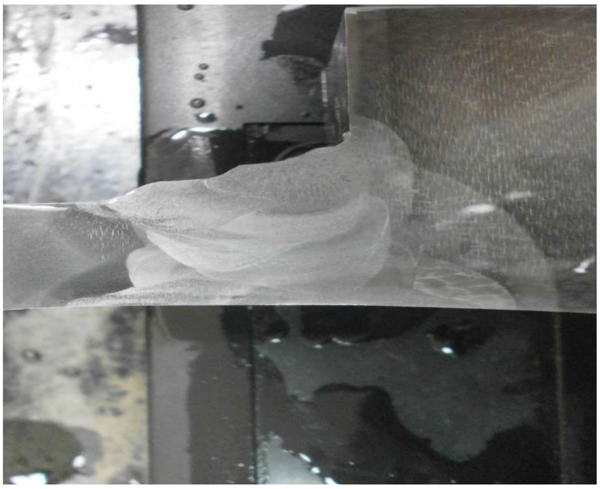


Fig. 5. Macro section in the area rail base

The hardness of the welded joint at the base of the rail made of R260 material and the block made of Cogidur material in the characteristic zones of the welded joint (BM - base material; HAZ - heat-affected zone; WM - weld metal) is presented in Tab. 5.

Tab. 5. Hardness of the welded joint

Rail base (54G2- EN 14811) /R260					
1	BM	280	5	HAZ	290
2	BM	285	6	HAZ	287
11		WM		345	
Block Cogidur /17MnCr5-3; Wr.Nr. 1.8715					
7	HAZ	280	3	BM	408
8	HAZ	288	4	BM	404
13		WM		309	

3.3. Fatigue testing

The fatigue testing was performed on the AW-RBW sample (block/Cogidur – rail 54G2/R260), following procedure T15002P01. The sample was 1200mm in length and was welded using the FCAW-S process at the company VOSSLOH MIN SKRETNICE in Niš. The fatigue test was conducted at the Vossloh Cogifer Technology Center in Reichshoffen, France (Fig. 6). The distance between the supports was 1000mm, and two laser sensors were used to measure the amplitude. Prior to testing, the hydraulic cylinder was certified, and the laser sensors were calibrated.

Fig. 6. Fracture testing machine

Fatigue testing was performed under variable loading with a frequency between 5 and 9 Hz (Tab 6) and an asymmetry factor of R=0.1. The criterion for a good welded joint is that after 3,000,000 cycles, there are no cracks in the welded joint. Calibration was performed directly on the test specimen. A 350Ω single-direction strain gauge was attached to the center of the rail base, 5mm from the weld.

Tab. 6. Fatigue testing parameters

No. cycles	Frekv. (Hz)	L1 Ampl. (mm)	L3 ampl. (mm)	Stress (MPa)
1.000 (calibration)	7	0,91	1,01	12,5-129,8
700.000	5	0,94	0,96	13,5-130,1
3.000.000	9	0,92	0,95	13,2-129,6

Based on the fatigue testing, after 3,000,000 cycles of variable loading (R=0.1) that induced stresses in the welded joint ranging from 13 MPa to 130 MPa, no cracks were observed in the welded joint, as clearly seen on the specimen after penetrant testing (Fig. 7).

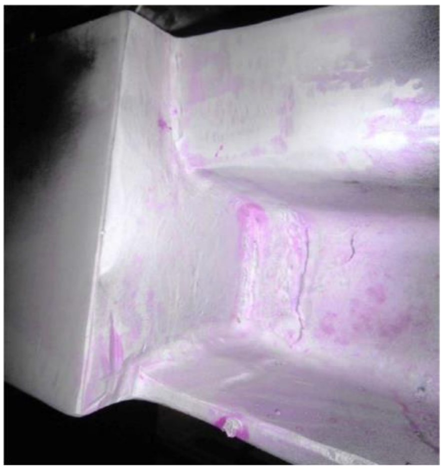


Fig. 7. Appearance of the specimen after penetrant testing

4. CONCLUSION

Grooved rail (also known as girder rail) is a common tram rail used by modern tram. Due to the asymmetric cross-section of the girder rail, the welding process of the girder rail is complex, the technical requirements are high, and the welding is difficult. Compared with standard steel rails, more sophisticated welding techniques are required. The paper presents the successful welding technology of tram rail 54G2 R260 and Cogidur block is a welding process 114 that uses a cored wire and generally uses similar equipment to the MAG process, but without the use of shielding gas, which is confirmed by testing the welded joint by non-destructive methods by determining the profile hardness of the welded joint and dynamic fatigue testing.

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PREVENTIVE MAINTENANCE IN RAILWAY VEHICLES USING NEW TECHNOLOGIES

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Abstract *– Preventive maintenance is essential for the safe and efficient operation of railway vehicles. This paper introduces a laser scanner system developed to measure critical wheel profile parameters, including the qR value (wheel profile conformity index), flange height (Sh), and flange thickness (Sd). These parameters are crucial for monitoring wheel wear and ensuring proper wheel-rail interaction. The laser scanning system provides real-time, high-precision measurements, enabling early detection of wear patterns that could lead to failures if left unaddressed. This non-contact, automated technology integrates seamlessly into existing maintenance workflows, reducing human error and enhancing decision-making capabilities. Maintenance teams can use the data to plan predictive interventions, reducing downtime, extending the life of both wheels and rails, and minimizing maintenance costs. The system has been tested in operational environments, demonstrating its effectiveness in improving the reliability and safety of railway vehicles. By offering a more efficient approach to wheel monitoring, this technology contributes to the future of predictive maintenance in the railway industry.*

Keywords – preventive maintenance, railway vehicle, wheel profile, inspection, flange.

1. INTRODUCTION

The condition of railway vehicle wheels is a key factor in ensuring safety and operational reliability. According to the Regulation on the Maintenance of Railway Vehicles issued by the Serbian Railways Directorate [1], regular preventive maintenance is essential to reduce the risk of wear-related failures and ensure the longevity of railway components. While traditional manual inspections are common practice, they are often time-consuming and prone to human error [2]. As railway systems evolve, the need for advanced inspection technologies has become evident. Tools like the Goldschmidt WM3 Wheel Measurement System [3] and Graw's Electronic Wheel Wear Caliper [4] offer non-contact, high-precision measurements, significantly improving the accuracy of wheel condition assessments.

Key parameters such as qR (wheel profile conformity), flange height (Sh), and flange thickness (Sd) are critical for ensuring safe wheel-rail interaction [5]. As highlighted in Maintenance of Railway Vehicles by Stamenković [6], the implementation of modern technologies in the maintenance process enables railway operators to detect early signs of wear, allowing for timely intervention and reducing the likelihood of critical failures. By adopting predictive maintenance strategies, which leverage real-time data from laser scanning and other advanced condition-monitoring systems, railway operators can optimize maintenance schedules and minimize downtime [7][8].

This paper presents a novel laser scanning system designed to further improve the precision of railway vehicle wheel inspections. It builds on prior studies that demonstrate the effectiveness of automated measurement systems in reducing human error and streamlining maintenance procedures [9]. The proposed system offers a comprehensive solution for continuous wheel monitoring, enhancing both safety and operational efficiency across the railway industry. By integrating appropriate software, preventive

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maintenance of rolling stock can be achieved. This would provide operators with more flexibility to organize better-planned wheel rim replacements. While operators have data on the number of kilometers a wheel has run, the terrain configuration and rail conditions have a greater impact on wheel rim wear. Therefore, incorporating wheel rim measurement with overhead software would be a valuable step forward.

2. MODERN MEASURING DEVICES

To enhance the efficiency of railway vehicle maintenance, a variety of advanced detection systems have been developed. These systems can be either installed directly on the vehicle or positioned along the track, allowing for real-time identification of potential failures during the vehicle's operation. By leveraging these technologies, maintenance teams can plan necessary interventions during scheduled downtime, minimizing disruption to service. Modern diagnostic tools such as optical cameras, thermal imaging cameras, and laser measurement systems have played a key role in enabling this proactive approach. [10]

Assessing the condition and lifespan of railway wheels requires close monitoring of critical factors, including the state of the rolling surface, the profile of the wheel rim, and the detection of stress or cracks in the wheel structure. [6]

Advanced diagnostic systems have been developed specifically for use in depots, where control inspections can be conducted more efficiently and completed in a significantly shorter time. The primary objective of these systems is to provide rapid and accurate diagnoses of defects, allowing maintenance teams to identify faulty components with minimal inspection time, thus improving overall maintenance productivity. Such devices can be seen in Figs. 1 & 2.

Fig. 1.Device for measuring wheel rim parameters [4]

Laser for distance measuring, that is the key technology parameter, has always some mistake during the measurement and this is the well know thing. Company Elag designed more sophisticated solution that gives more accurate by integrating laser that is moving during the measurement and always have same position to wheel flange.

Fig. 2. Device for measuring wheel rim made by company Elag

3. WHEEL PARAMETERS MEASURING DEVICES

The wheel rim profile, as defined by UIC 510-2 standards, plays a critical role in enabling the vehicle to move safely on rails. It directly influences key factors such as vehicle stability, ride smoothness, and the rate of wear on both wheels and rails. Over time, as the vehicle operates on the rails, the tread surface of the wheel is subjected to wear and deformation. If a visual inspection identifies damage that could compromise the geometric properties of the wheel, precise measurements of the rim profile are necessary. The differences between the standard wheel rim profile and the damaged profile are shown in figure 3.

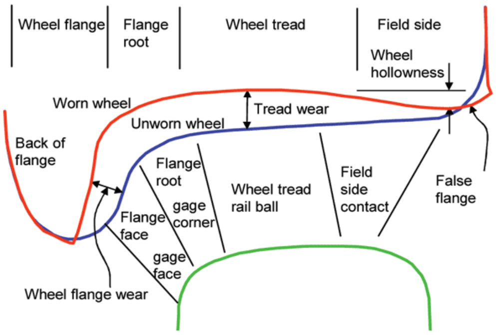

Fig. 3. Difference between unworn and worn wheel

3.1. Universal qR measuring device

The universal qR measuring device (see Fig. 4) is commonly used to obtain critical parameters of the wheel rim, such as rim height, thickness, and sharpness. While this analog device is widely relied upon in the railway industry, it does come with certain limitations. One of the primary concerns is that the device depends on manual readings and data entry by operators, which introduces the potential for human error. These errors can occur during both the measurement process and the manual input of data, leading to inaccuracies that may compromise the quality of the inspection. Additionally, the reliance on human operators increases the time needed for inspections, particularly when precision is crucial. This highlights the need for more automated, digital solutions that can reduce human involvement, improve accuracy, and streamline the entire measurement process.

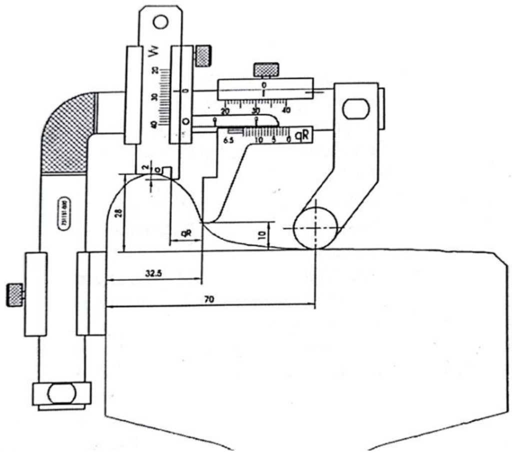

Fig. 4. Universal qR measuring device [6]

3.2. Non-contact laser wheel profile measuring device

On the other hand, key wheel rim parameters can also be determined using a laser device, which provides non-contact, high-precision measurements. Unlike traditional methods, laser profilometers scan the entire profile of the wheel rim, capturing the exact coordinates of multiple points along the rim's surface. These data points are then processed to generate accurate measurements of critical parameters such as rim height, thickness, and sharpness. This method not only eliminates the risk of human error but also offers significantly higher accuracy and repeatability. By automating the process, laser devices can provide real-time data that allow for more efficient and reliable assessments of wheel condition, ensuring the safety and longevity of the vehicle. Developed device was tested in real life scenarios, wheel rim was scanned and wheel profile parameters were obtained with it (see Figure 5).

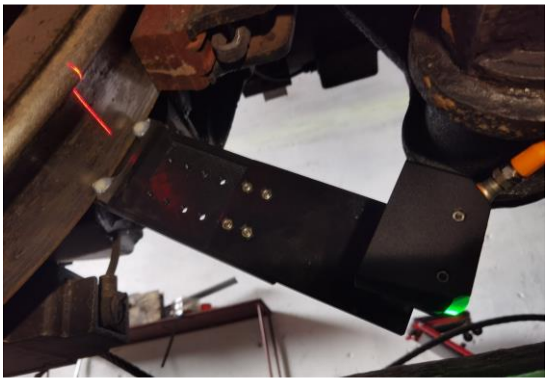

Fig. 5. Wheel rim profile scanning

This device scans nearly the entire width of the wheel rim, providing significantly more detailed information about the condition of the wheel profile compared to traditional measuring tools. Unlike conventional devices, which may only capture specific points or sections of the rim, the laser system generates a complete profile line. This comprehensive data offers a far more accurate and thorough insight into the wheel’s condition, enabling better assessments and more informed maintenance decisions. By capturing the full profile, the device allows for a clearer understanding of wear patterns and potential issues, ultimately leading to improved safety and efficiency in railway operations.

The collected data is then processed, with the measured wheel profile displayed alongside the reference wheel profile for comparison. This side-by-side visualization allows for an easy and accurate assessment of any deviations or wear in the wheel rim. In addition to the visual comparison, key parameters such as qR measurement, flange height (Sh), and flange thickness (Sd) are also displayed, providing crucial insights into the overall condition of the wheel. The output generated by the device offers a comprehensive overview of the wheel's status, as shown in Figure 6.

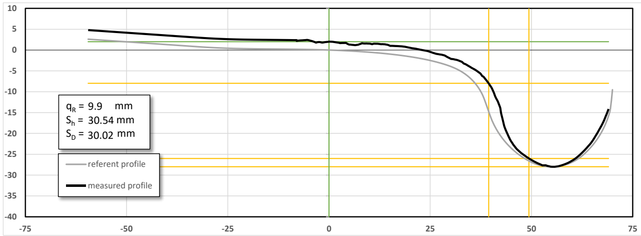

Fig. 6. Example of measured wheel profile

3.3. Comparing of two methods

Both the traditional and advanced laser-based methods for measuring the wheel rim profile are effective, but each comes with its own set of advantages and disadvantages. The traditional measuring device, for instance, is highly portable and simple to use. It doesn't rely on batteries, external hardware, or software, which makes it easy to operate in a variety of settings. However, as previously mentioned, the traditional method has some drawbacks, such as the potential for human error during data collection and manual input, as well as the time-consuming nature of the process.

On the other hand, the laser measuring device offers several key advantages, particularly in terms of accuracy and efficiency. This device provides instant, precise measurements without requiring additional manual steps, making the process straightforward and reducing the chance of operator error. The device is secured to the wheel using strong neodymium magnets, ensuring stability during the scanning process. Once positioned, the operator simply presses a button to initiate the scan. The device then scans the entire wheel rim profile, displaying the data immediately for the operator to review. The operator can then decide whether to save the data to the corresponding wheel of the railway vehicle or dismiss the measurement, providing flexibility and control in the inspection process.

Despite its many advantages, the laser measuring device does have some limitations that should be considered. One of the primary drawbacks is that it requires additional hardware beyond the scanning tool itself. This includes a portable suitcase containing essential components such as batteries to power the device, a touch screen for displaying real-time information, and a Raspberry Pi microcontroller to process the collected data. Additionally, the system features several knobs and switches for ease of use, as well as the scanning head equipped with an IoT device that facilitates data transmission to the microcontroller. While these components enhance the device’s capabilities, they also introduce a level of complexity and require more preparation and maintenance than the traditional method. The fully assembled laser measuring device, stored in its portable case along with all the essential components for wheel rim measurement can be seen in Figure 7.

Fig. 7. Laser measuring device housed in its portable suitcase for wheel rim inspection

4. CONCLUSION

This paper has presented a comprehensive solution for enhancing the inspection and maintenance processes of railway vehicles. The proposed solution can be seamlessly integrated into existing maintenance systems, offering a significant improvement in both efficiency and accuracy. By utilizing advanced technologies, such as laser scanning and automated measurement systems, the inspection process becomes more streamlined, reducing the reliance on manual labor and minimizing human error.

One of the key advantages of the system is its ability to store measured data on cloud-based platforms, enabling remote access and real-time monitoring from anywhere in the world. This cloud integration aligns perfectly with the principles of Industry 4.0, where digitalization, data exchange, and automation are essential for improving operational efficiency. The ease with which this technology can be implemented into Industry 4.0 frameworks ensures that railway operators can optimize maintenance schedules, reduce downtime, and make data-driven decisions that improve the overall performance of the railway system.

Furthermore, the adoption of this technology will significantly enhance the safety and reliability of railway vehicles. By facilitating faster and more accurate inspections, maintenance teams can focus their attention on the most critical components, prioritizing those that pose the greatest risk to operational safety. As a result, the risk of unexpected failures will be reduced, and the lifespan of both the wheels and the entire vehicle will be extended. In conclusion, the integration of these technologies into the maintenance workflow represents a pivotal step forward in ensuring the future sustainability and reliability of railway transport.

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IMPROVEMENT OF SPARE PARTS STOCK MANAGEMENT SYSTEM FOR LOCOMOTIVE DEPOT

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Abstract *– This paper analyzes the inventory management system of spare parts for Locomotive Depot - Sofia. Considering the large inventory park of the depot, mainly the repair works related to the electric locomotives, series 44, 45, 61, as well as diesel-hydraulic locomotives, series 52 and 55 were considered. The periodicity of planned inspections and repairs is determined on the basis of traveled kilometers or working days. Exploitational inspections are provided for in the locomotive turnover schedule. In order to make an optimal delivery of spare parts in Locomotive Depot - Sofia, it is necessary to carry out analyzes and choose a system for managing the inventory. The decrease in the average availability of spare parts is related to an increase in the number of deliveries during the year, respectively a decrease in the quantity in one delivery. The higher the number of deliveries during the year, the higher the costs of deliveries. Inventory management is related to determining the optimal quantity in one delivery, as well as the optimal number of orders that will balance both types of costs and minimize them without affecting the continuous production.*

Keywords – inventory, parts stock, locomotive depot.

1. INTRODUCTION

Establishing an accurate spare parts supply model for the Locomotive Depot has tremendous benefits on the overall operation of the depot and the Train Running Schedule. In terms of their size, number, location and purpose, all facilities and equipment of the depot must correspond to the type and series of the serviced electric locomotives, and to ensure the performance of all work on their maintenance and repair, in accordance with the specified mileage, program and repair time. In accordance with the production program, the available materials and raw materials, stored in the warehouses of the depot/regions are checked and a request is prepared by product types for the deficient materials.

The supply of spare parts at the right time and in the right quantities, combined with an appropriate inventory model, will facilitate the supply management and repair activities at the depot, as well as minimize and balance the costs of these activities. This will lead to high-quality, accurate repair work, the implementation of the Annual Repair Plan, a reduction in the number of accidental repairs, which will also achieve greater accuracy in the application of annual requests for spare parts, and last but not least, you will ensure a reliable and fail-safe rolling stock to meet the needs of the Train Running Schedule.

The analysis is based on data from the Sofia Locomotive Depot. Considering the large inventory of the depot, mainly the repair works related to the electric locomotives of the 44, 45, 61 series, as well as the diesel-hydraulic locomotives of the 52 and 55 series were considered.

2. STRUCTURE OF THE LOCOMOTIVE DEPOT - SOFIA

The ongoing reforms in the system of "Holding - Bulgarian State Railways" EAD [1] provide clear outlines at the present moment for the function and purpose of the locomotive depot. Locomotive depot Sofia, with its Organization of work in repair [2] and improvement of working conditions [3] and their training [4] is a division included in the organizational and management structure of "BDZ - Passenger Transport" EOOD [5] and Division for passenger transport Sofia. The extent of inspections and repairs is determined by the Depot Repair Regulations [6], [7] and [8] for maintenance for individual series of locomotives and locomotives.

The planning of the repair [2] at the depot it is done for a year, quarterly, monthly and weekly. On the basis of the requests submitted by the regions, based on mileage and days worked, for Major Periodic Repair (MaRP), Hoist repair /HR/, Medium Repair (MR) and Capital Repairs (CR) based on mileage and days worked, the Locomotive Depot

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submits at the end of the current year, if necessary, the plans are added or updated. Purchasing planning is annual and operational /weekly and daily/, which is part of an organizational chart of material flows. Operational inspections are provided for in the schedule for the turnover of locomotives.

According to the reports made, a total of 312 repairs are planned by schedule at the Sofia Locomotive Depot for the year 2023, are shown in Tab. 1: Technical inspections /TI/; Minor periodical repair /MiPR/; Major periodical repair / MaRP /; Hoist repair /HR/, and 402 were implemented, which also depends on [9].

Tab. 1. Data on planned and occasional repairs in the Sofia Locomotive Depot by

for 2023 y.	TI		MiPR		MaPR		HR	
Locomotive series	schedule	implemented	schedule	implemented	schedule	implemented	schedule	implemented
52 00	71	82	19	16	6	7	1	3
55 00	75	97	18	23	1	2	2	1
44 00	16	22	11	9	2	4	4	5
45 00	38	41	10	12			5	2
61 00	15	54	14	19			4	3
	215	296	72	79	9	13	16	14

Between-repair runs for the inspections and repairs of series 44 and series 45 electric locomotives, are shown in Fig. 1.

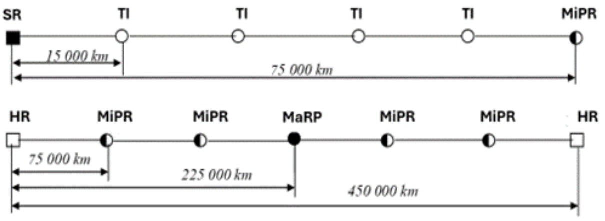

Fig.1. Between-repair runs for series 44 and series 45

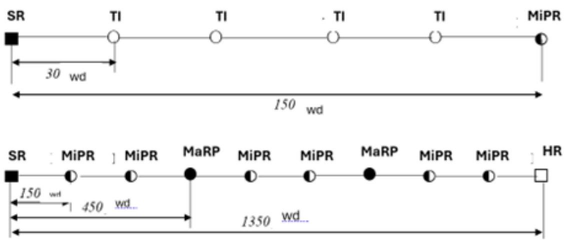

Fig.2. Between-repair runs for series 61

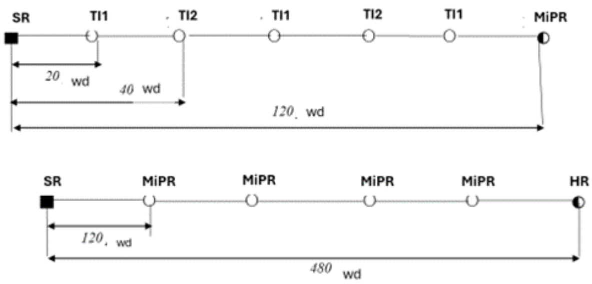

Fig.3. Between-repair runs for series 52

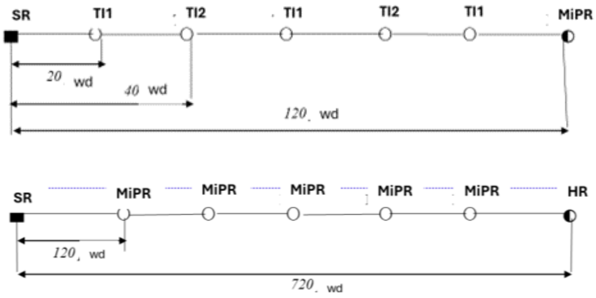

Fig.4. Between-repair runs for series 55

According to the Repair Plan for:

Tab. 2. Data on planned repairs at the Sofia Locomotive Depot by series and by month

month	series 44	series 45	series 61	series 52	series 55
January	14	1	6	6	2
February	9	1	3	1	1
March	11	1	5	6	2
April	10	1	4	0	1
May	12	1	5	5	2
June	8	1	3	1	1
July	9	1	5	5	2
August	9	1	2	0	1
September	8	1	5	5	2
October	7	1	3	1	1
November	11	1	4	6	2
December	10	1	3	1	1
total:	118	12	48	37	18

For the year 2023, the Sofia Locomotive Depot incurred costs for spare parts in the amount of 86,329,000 BGN. According to these prescriptions, the series of locomotives taken into account is as follows in [6], [2].

After a statistical analysis of the consumption of spare parts and due to their huge number, the report will consider the most frequently used in repairs for each of the presented series of locomotives:

- For Series 44: accumulator batteries, contacts, brake pads and brushes;
- For Series 45: flanges, brake pads, brushes;
- For Series 61: brake pads, brushes;
- For Series 52: accumulator batteries, semmering;
- For Series 55: accumulator batteries, brake pads, semmering;

3. INVENTORY MANAGEMENT SYSTEM

To do selection of a spare parts inventory management system at the Sofia Locomotive Depot and to determine the size and frequency of the order, we need to examine the 4 approaches and choose the one in which the costs are minimal. This is due to the fact that the organization of all deliveries is accompanied by costs that do not depend on the quantity of spare parts requested in them. These costs are minimal when the entire need for spare parts for the year is requested and delivered at once, but at the expense of increasing storage costs. We determine for an order approximately equal to 818 BGN, which includes: salary costs of procurement employees and all related to the order, business trip costs, fuel costs, telephone costs, other transport costs for delivery, etc.. And the annual costs for storage for each spare part are approximately 28% of the unit price, including the costs of salaries of warehouse workers, security costs, depreciation, etc. The price of each item is in BGN.

- For Series 44 as the annual storage period we get for 1 item per: Accumulator batterie 147,98; Contact 7,88; Brake pad 30,65; Brushe 14,88;
- For Series 45 as the annual storage period we get for 1 item per: Rim 951,08; Brake pad 36,47; Brushe 17,21;
- For Series 61 as the annual storage period we get for 1 item per: Brake pad 32,04; Brushe 15,15;
- For Series 52 as the annual storage period we get for 1 item per: Accumulator batterie 271,16; Semmering 18,30;
- For Series 55 as the annual storage period we get for 1 item per: Accumulator batterie 271,57; Brake pad 33,74; Semmering 18,30;

4. USED SUPPLY MANAGEMENT MODELS

These are models of the type inventory comparison:

- One Time Buy;
- Lot For Lot;
- Simple Economic order quantity (EOQ);
- Silver-Meal Algorithm;

4.1. Application of used models

There is an opportunity to further reduce the cost of an order, and if possible, spare parts for several series of locomotives from the relevant company or another division of BDZ can be supplied with one order. In this case, it is possible to combine the optimal orders for the spare parts discussed in the following way:

Tab. 3. Presentation of optimal solutions by series

	Series 44				Series 45			Series 61		Series 52		Series 55		
Month	Accumulator batteries	Contacts	Brake pads	Brushes	Rims	Brake pads	Brushes	Brake pads	Brushes	Accumulator batteries	Semmering	Accumulator batteries	Brake pads	Semmering
January	13	195	6772	2636	9	6486	1099	6663	1008	16	3609	13	540	2636
February	0	0	0	0	0	0	0	0	0	0	0	0	650	0
March	0	0	0	0	0	0	0	0	0	0	0	0	850	0
April	0	0	0	0	0	0	0	0	1008	0	0	0	570	0
Maybe	0	0	0	0	0	0	1099	0	0	0	0	0	600	0
June	0	0	0	0	0	0	0	0	0	0	0	0	489	0
July	0	0	0	0	0	0	0	0	0	0	3163	0	486	0
August	0	0	0	0	0	0	1099	0	0	0	0	0	651	0
September	0	0	0	0	9	0	0	0	1008	0	0	0	398	0
October	0	0	0	0	0	0	0	0	0	0	0	0	678	0
November	0	0	0	0	0	0	0	0	0	0	0	0	440	0
December	0	0	0	0	0	0	0	0	0	0	0	0	462	0

If we assume that there is an opportunity to combine the orders, then the total costs for purchase, delivery and storage at the Sofia Locomotive Depot will be:

Tab. 4. Costs for ordering by series

	Costs	Costs of combined orders	Costs saved
Series 44	12401	9947	2454
Series 45	10212	8576	1636
Series 61	9264	8446	818
Series 52	9614	8796	818
Series 55	17392	15756	1636
	58882	**51520**	**7362**

So in the month of January, instead of making 18 orders, each of which costs BGN 818 or BGN 28,853, only 1 will be made with BGN 818 costs or BGN 13,906 less. In the months of April, May, August and September, one order was made at a cost of BGN 818. In this way, the total costs for orders and storage for the depot will be BGN 51,520, or BGN 7,362 less, instead of BGN 58,882.

4.2. Results

After the calculations made according to the listed inventory management models, are presented the optimal solutions, where the price of each item is in BGN:

For Series 44:

- 13 Accumulator batteries, which will be supplied on the model One Time Buy, with costs 1045,89;
- 195 Contacts, which will be supplied on the model One Time Buy, with costs 1006,10;
- 6772 Brake pads, which will be supplied on the model One Time Buy, with costs 7153,31;
- 2636 Brushes, which will be supplied on the model One Time Buy, with costs 3195,58;

For Series 45:

- 13 Rims, which will be supplied on the model Simple EOQ, with costs 2033,06;
- 6484 Brake pads, which will be supplied on the model One Time Buy, with costs 4881,83;
- 3076 Brushes, which will be supplied on the model Simple EOQ, with costs 3297,05;

For Series 61:

- 6663 Brake pads, which will be supplied on the model One Time Buy, with costs 4430,00;
- 2605 Brushes, which will be supplied on the model Simple EOQ, with costs 4834,12;

For Series 52:

- 16 Accumulator batteries, which will be supplied on the model One Time Buy, with costs 1368,45;
- 6772 Semmerings, which will be supplied on the model Silver-Meal Algorithm, with costs 8245,11;

For Series 55:

- 13 Accumulator batteries, which will be supplied on the model One Time Buy или Simple EOQ , with costs1236,22;
- 6814 Brake pads, which will be supplied on the model Lot For Lot, with costs 9816;
- 2636 Semmerings, which will be supplied on the model One Time Buy, with costs 6339,54;

Tab. 4. Inventory for each series, by months

Month	Series 44				Series 45			Series 61		Series 52		Series 55		
	Accumulator batteries	Contacts	Brake pads	Brushes	Rims	Brake pads	Brushes	Brake pads	Brushes	Accumulator batteries	Semmering	Accumulator batteries	Brake pads	Semmering
January	13	195	6772	2636	13	6486	3076	6663	2605	16	6772	13	6814	2636
February	11	173	5992	2335	11	5696	2875	5923	2305	14	5992	11	6274	2335
March	10	155	5452	2050	10	5176	2517	5403	2020	14	5452	10	5624	2050
April	9	140	4844	1830	9	4672	2297	4803	1800	11	4844	9	4774	1830
Maybe	8	123	4273	1584	8	4201	2051	4233	1560	11	4273	8	4204	1584
June	7	107	3661	1364	7	3580	1726	3613	1350	7	3661	7	3604	1364
July	6	92	3163	1110	6	2993	1472	3115	1100	7	3163	6	3115	1110
August	5	76	2479	890	5	2528	1070	2433	880	6	2479	5	2629	890
September	4	62	1918	701	4	1959	781	1898	700	6	1918	4	1978	701
October	3	46	1420	555	3	1457	645	1400	560	5	1420	3	1580	555
November	2	33	842	366	2	879	356	830	370	3	842	2	902	366
December	1	16	412	146	1	451	126	410	148	3	412	1	462	146

Thus, in the locomotive depot there will be the following stock of the examined spare parts for each series, by months.

5. CONCLUSION

Inventory management is related to determining the optimal quantity in one delivery, as well as the optimal number of orders that will balance both types of costs and minimize them without affecting continuous production.

Creating an accurate spare parts supply model for the Locomotive Depot has tremendous benefits on the overall operation of the depot. On-time delivery and in the right quantities of spare parts, combined with an appropriate inventory management model, will facilitate supply and repair activities in the depot, as well as minimize and balance the costs of these activities. This, in turn, will lead to quality repair work, accurate implementation of the Annual Repair Plan, reduction in the number of accidental repairs, which will result in greater accuracy in the development of annual requests for spare parts and, last but not least, ensuring reliable and trouble-free transportation of locomotives.

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DESIGNING THE WEAR AND TEAR COMPONENT IN THE STRUCTURE OF TRACK ACCESS CHARGES

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***Abstract** – This paper aims to provide and analyse the structure of Track Access Charges (TAC) for small railways, with a focus on the wear and tear component and its elements. A review and analysis of the wear and tear component in the TAC models for selected small railways have been conducted. The impact of wear and tear component in freight train charges, as well as the ratio between wear and tear charges and infrastructure capacity charges within the total TAC, has been thoroughly analyzed. The paper provides a discussion on the selection, representation, and evaluation of the impact of specific elements on the wear and tear of rails in TAC determination models. The research contributes to understanding the complex interactions between elements within the TAC structure, based on the experiences of railway infrastructure managers to date. The results of this research indicate that infrastructure managers of small railways have not developed a clear understanding of the factors influencing the wear and tear costs of infrastructure, leading to heterogeneity in the structure and level of Track Access Charges (TAC).*

Keywords – railway network, wear and tear, train weight, infrastructure manager.

1. INTRODUCTION

Regulation 2015/909/EU from 2015 is currently the latest document published by the EU concerning the rules for designing Track Access Charges (TAC). This legal act effectively defines the limitations in the scope of direct costs incurred as a result of operating the train service [4]. The term "structure of TAC" refers to the components of the TAC and their elements used for calculation of the charges level, along with their interrelationships, i.e., connectivity [1]. The charges components and their elements (variables, coefficients, weights) should reflect the allocation of infrastructure costs according to track categories, traffic types (passenger or freight), market segments, as well as according to vehicle categories and defined services [2]. By selecting elements in the TAC structure, evaluating them, and establishing relationships between these elements, the infrastructure manager encourages specific operator behaviors, as well as the rationalization of certain costs incurred by the operators.

In overview of papers focused on TAC modeling, few papers provide a critical review of the structure of TAC components or explain the reasons for introducing specific elements. There is a particular lack of research dedicated to small railways networks, as well as their specificities that are crucial for designing TAC. Small countries with their small railways networks often face challenges such as resource constraints or limited opportunities to achieve market competition within a small railway network. The aim of this paper is research the structure of TAC for small railways, with a particular focus on the wear and tear component and its elements. Based on the criteria such as network length under European conditions (up to 4,000 km, as adopted in this research) and the intensity of its use, a cluster of twelve small European railways has been defined. The cluster includes the railways of Montenegro, Luxembourg, North Macedonia, Slovenia, Greece, Portugal, Lithuania, Latvia, Croatia, Serbia, Slovakia, and Bulgaria.

A review of the wear and tear component and its elements for this selected cluster of small railways has been done, the relative share of the wear and tear component in the TAC structure for freight trains of different weights has been analyzed. The research contributes to understanding the complex interactions

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between elements within the TAC structure, thereby providing relevant guidelines for creating a charge model for small railways that would be suitable for their needs and constraints.

2. ELEMENTS OF THE WEAR AND TEAR COMPONENT IN THE TAC STRUCTURE

According to the legislative framework, the TAC structure, in addition to being based on the direct costs incurred as a result of operating the train service, must also be transparent, clear, and standardized for all railway operators. The general formula for calculating infrastructure charges for the minimum access package (MAP) can be represented as the sum of the following components [1]:

$$C = C_{ad} + C_{op} + C_{wt} + C_{oh}$$

where:

C_{ad} - the charge component that represents the costs of requests for railway infrastructure capacity,

C_{op} - the charge component that reflects the use of the railway infrastructure operational costs,

C_{wt} - the charge component that reflects the costs of infrastructure wear and tear, and

C_{oh} - the charge component that reflects the costs of maintaining electrical supply equipment for traction current (if the route is electrified).

The TAC calculation formula, as presented, provides insight into the method of cost calculation by the place of origin and allows railway operators to calculate the effect of cost rationalization by optimizing their expenses. The focus of this research is the wear and tear component (C_{wt}), its elements, recognizability, and relative share in the charges for freight trains within the defined cluster of small railways.

Depending on how it is structured and presented to railway operators, charges are classified into four categories: simple, simple +, multiplicative, and additive [7,8]. This classification considers the number of components, the number of elements, the measurement units used, and their relationships. It has also been established that the structure of charges may or may not be based on market economic principles of supply and demand, which primarily depends on the size of the market and the competitiveness of the railway within it [3]. The structure of charges varies from country to country, and this has so far been justified by the specificities of the particular railway or the different objectives that need to be achieved. However, the significant heterogeneity of TAC models suggests that the allocation of costs, as well as their management by infrastructure managers (within the TAC structure), is highly questionable.

By analyzing Network Statements [6] published on the websites of the selected cluster of infrastructure managers, Table 1 provides an overview of the type of TAC calculation formulas an d the elements in the wear and tear component. The railway infrastructure managers of Montenegro (MNE), Luxembourg (LU), North Macedonia (MK), Slovenia (SI), Portugal (PT), and Croatia (HR) impose charges for the MAP based solely on train kilometers, while in Latvia (LV), Greece (GR), Serbia (RS), Slovakia (SK) and Bulgaria (BG) charges are imposed based on both train kilometers and gross tonne kilometers. Within the analyzed group of countries, Lithuania (LT) is an exception, where the infrastructure manager imposes charges solely based on gross tonne kilometers. The wear and tear component is generally clearly distinguished in the simple and additive types of formulas, as seen in RS, LT, LV, GR, SK, and BG. In Luxembourg (LU), the formula is also additive, but the wear and tear and capacity components are incorporated into a multiplicative term within the additive formula. In Portugal (PT), the charge is calculated as the product of two elements: the route length and the unit price per train kilometer, which varies depending on the line, type of traction, timetable, and market segment. In such a designed formula, the wear and tear component is not distinguishable.

Tab. 1. Overview of TAC Calculation Formula Types and Elements in Wear and Tear Component

Country	Type of TAC calculation formula	TAC calculation		Elements of wear and tear component		
		train km	gross tonne km	Weight (train)	Weight coefficient	Speed
Montenegro (MNE)	multiplicative	✓			✓	
Luxembourg (LU)	additive	✓			✓	
North Macedonia (MK)	multiplicative	✓			✓	✓
Slovenia (SI)	multiplicative	✓			✓	✓
Lithuania (LT)	additive		✓	✓		
Latvia (LV)	additive	✓	✓	✓		
Greece (GR)	additive	✓	✓	✓		
Portugal (PT)	simple	✓				
Croatia (HR)	multiplicative	✓			✓	
Serbia (RS)	simple +	✓	✓	✓		
Slovakia (SK)	additive	✓	✓	✓		
Bulgaria (BG)	additive	✓	✓	✓		

In Table 1, the influential elements of the wear and tear component (gross train weight, infrastructure wear and tear coefficient as a function of gross train weight, and speed) are also identified and highlighted. In some countries, wear and tear coefficients, which vary depending on the gross train weight or train type, are used to calculate wear and tear charges (MNE, LU, MK, SI, and HR), while in other countries, the actual gross train weight is used (LT, LV, GR, RS, SK, and BG). When the wear and tear component is determined directly based on the gross train weight, the train's weight is multiplied by the unit charge per gross tonne kilometer. When the wear and tear component is a function of the wear and tear coefficient, infrastructure managers combine the impact of capacity usage and wear and tear in a multiplicative formula, where the measurement unit for capacity (train kilometers) is combined with the wear and tear coefficient. The wear and tear coefficient is presented in intervals (ranging from) with a more or less developed scale of train weight intervals or depending on the type of freight trains. It is important to note that determining the wear and tear coefficient is extremely complex and requires more precise cost allocation and monitoring over a longer period [5].

3. THE SHARE OF THE WEAR AND TEAR COMPONENT IN THE TAC STRUCTURE

The length of the reference route, on which the impact of train weight on the wear and tear component was examined, was determined based on the average value of the mean transport distance for one ton of freight on the selected small railways, amounting to 220 km [9]. This is an average value, considering all cluster participants equally, even though they do not achieve the same transport volumes. For a relevant analysis, it was further assumed that the entire route is electrified and located within the national territory, and that the reference route is on an international main line (first category line) that is not declared congested. It was also assumed that the freight train operates as a regular train with a regular path request and a maximum train speed of 80 km/h.

It is important to note that in the multiplicative TAC structure categories where the wear and tear coefficient is an element, it is not possible to accurately estimate the exact ratio between the track wear and tear component and the capacity component in the route charges. Therefore, different calculation mechanisms were applied to ensure approximate accuracy and consistency in analyzing the ratio between these two components. Bearing in mind the defined assumptions, figure 1 presents a comparative view of the share of the wear and tear component in the overal TAC structure for two categories of freight train weights: 960 t and 2,000 t. The adopted value of the characteristic freight train weight of 960 tonnes is taken from previous research [7,8] as the defined minimum train weight that ensures the competitiveness of freight transport by rail.

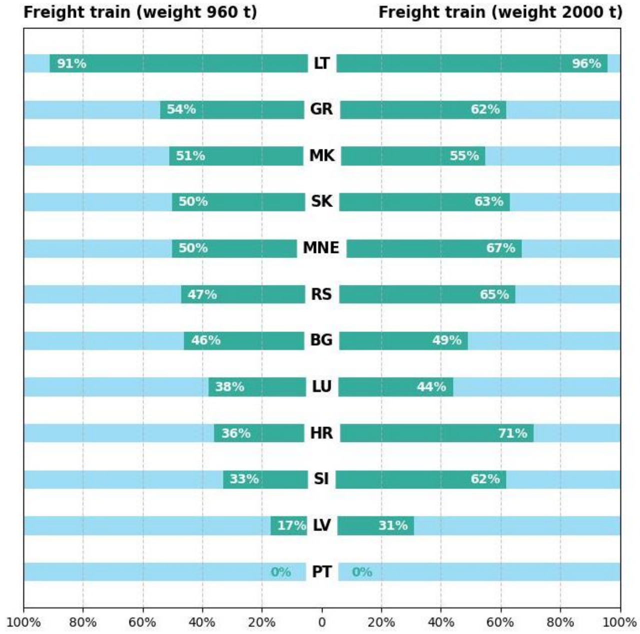

Fig. 1. Comparison of the wear and tear component contribution in the TAC structure for a freight train with weights of 960 t and 2000 t

For a characteristic freight train of 960 tonnes, the share of the wear and tear component in the TAC structure of the analyzed cluster of small railways varies significantly, ranging from 54% in Greece (GR) to 17% in Latvia (LV). This broad range highlights the different approaches to designing TAC structures and/or varying priorities in infrastructure management among these countries. Lithuania (LT) and Portugal (PT) are excluded from this analysis because their specific TAC structures prevent direct comparison with countries that redistribute charges between the wear and tear and capacity components.

In the following countries: GR, MK, SK, MNE, RS, and BG, the share of the wear and tear component is consistent at 46%-67% for both freight train weight categories, despite differences in the measurement units used for calculating charges and the TAC structure categories. In these countries, the share of the wear and tear component within the TAC structure remains relatively consistent, indicating shortcomings in the allocation of wear and tear costs and in the TAC methodology. In contrast, in SI and HR, a significant increase in the share of the wear and tear component is observed, rising from 33%-36% for 960-ton trains to 62%-71% for 2000-ton trains. This suggests that these countries place a different value on the impact of increased train weight when calculating infrastructure wear and tear charges, recognizing it as a factor that incurs additional infrastructure maintenance costs. Diagram 2 provides a clear view of the relative share of the wear and tear component and its significance within the TAC structure for the range of gross train weights from 600 to 2000 tonnes on the adopted reference route of 220 km.

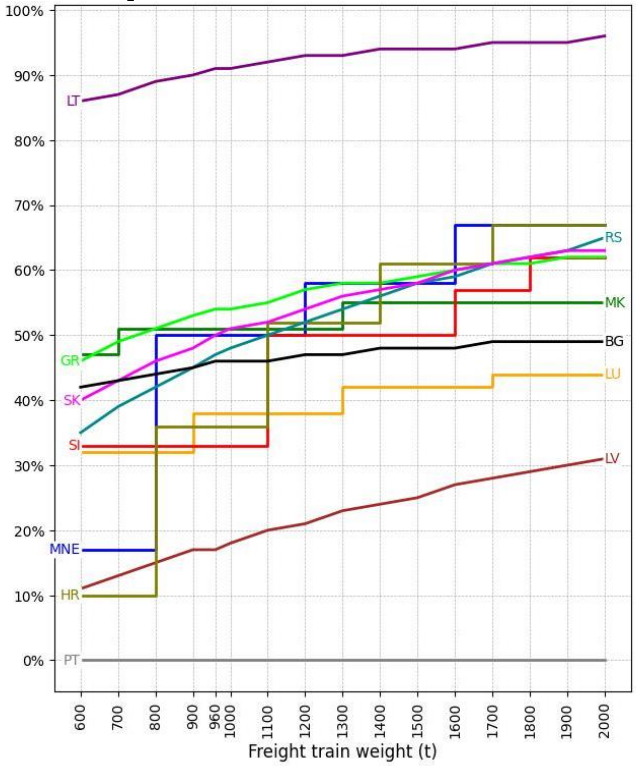

Fig. 2. Contribution of the wear and tear component to TAC

Growth trends vary significantly across countries. In some cases, the increase is gradual and continuous, while in others, there are stepped (discontinuous) changes due to the use of a wear and tear coefficient based on gross train weight as an element of the TAC structure. The stepped lines observed in MNE, LU, MK, SI, and HR indicate that charges are calculated based on defined gross train weight classes. The fewer the number of classes, or the wider the range of these classes, the more significant the increase in the relative share of the wear and tear component when moving from one train weight class to another.

4. CONCLUSION

Infrastructure managers do not publish the theoretical basis or conceptual framework of the adopted TAC model, which complicates the understanding of its structure and the measurability of the impact of individual factors. Nevertheless, gross train weight remains a key element in the TAC structure for determining the level of charges. However, the significant heterogeneity in the evaluation of the impact of gross train weight on the wear and tear component and its share within the TAC structure, as identified in this study, indicates that the allocation of infrastructure wear and tear costs by infrastructure managers is still at a low level. It is evident that infrastructure managers of small railways have not yet developed a clear understanding and assessment of the factors influencing infrastructure maintenance costs. The calculation models lack transparency, making it difficult to clearly and precisely determine the impact of different train weights on infrastructure maintenance costs and on the overall TAC structure. This research highlights significant differences in TAC structures for small railways, which sends a negative message to operators. Specifically, the varying assessments within the designed TAC calculation formula confuse and disorient operators, as they struggle to navigate and identify ways to reduce their TAC costs in their operations. This research is limited to small railways, and comprehensive conclusions require further analysis of TAC models for other European countries. A deeper understanding of these causes, factors, and relationships represents the direction of future research, which would contribute to the harmonization and improvement of the charging system within the Single European Railway Area.

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PROGRAM FOR PASSING PROFESSIONAL EXAM FOR POSITION OF MACHINE DRIVER EXPERIENCE AND CHALLENGES IN FUTURE

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Abstract *– The program of preparation for taking the professional exam for the position of train driver and the Program for taking the professional exam for the position of train driver are determined by the Rulebook on professional training, professional qualification and professional examination for the positions of railway workers, Annex 3, which was adopted by the Directorate of Railways on 30.05.2022 , Official Gazette of the Republic of Serbia No. 66/22 of June 10, 2022. In order for the train driver trainee to be able to pass the professional exam, it is necessary to pass the preparation for taking the professional exam as well as to master the program for passing the professional exam. The period of preparation and the program for taking the professional exam was reviewed from the current situation, an analysis was made of the preparation and program for taking the professional exam for the position of train driver. The main recommendation is that it is necessary to introduce practicing on simulators into the training program, because some special cases are insufficiently practiced or excluded from practice during the preparation for the professional exam and can only be dealt with in theory*

Keywords – professional exam,train driver,experiences,simulator for train drivers.

1. INTRODUCTION

This paper will present the program for taking the professional exam for the position of train driver, the current method and the experience. The professional exam determines the employee's knowledge to independently perform the work of a train driver. The traineeship of train driver candidates represents an important stage in their professional development because during their career they will face situations that require an accurate and quick reaction. With the introduction of new vihicles appeared the need to increase the level of knowledge and skills as well as to introduce simulators as an addition to the program for passing the train driver professional exam.

1.1. The preparation and program for taking the professional exam for the position of driver

The preparation and program for taking the professional exam is determined by the rulebook on professional training, qualification and examination Attachment 2 and Attachment 3. The time needed for preparation for passing the professional exam is determined by the rulebook and is diveded in 2 parts- 12 week period of introdoction to other work and 14 weeks of work under supervision of another train driver. In the first week the candidate will be introducted with the regulations on personal safety, safety and health at work and with the work organasation in the bussiness unit where the professional training is performed. Introducing to a certain jobs means acquiring skills and understanding the work process, getting familiar with the steps and procedures that are partf of those jobs. That means knowing the equipment, tools, facilities and devices that are used on those jobs, and specific skills and knowledge needed for those jobs. That also means knowing how to apply regulations relevant for that job and how that affects train drivers work, how to communicate between jobs and train drivers and how to collaborate with other employees. The program for passing the professional exam includes training, knowledge in vehicles and infrastructure. It also incluedes knowledge in safety regulations, trains braking, managing emergency situations and accidents. This part of the program is highlited as important because it enabales train drivers to assure safety while driving the train.This program includes compreehensive training and examining the theoretical and practical skills. Theorethical exam includes knowing towing vehicles and infrastructure which are key for safety and efficiency of a railway traffic.The ability to notice and react to driving

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irregularities, as well as dealing with accidents and incidents, are essential.The practical exam includes work in the field, where the commission evaluates the application of theoretical knowledge in practice. This includes knowledge of the towing vehicle, traffic and signal regulations, and infrastructure. Successfully passing these exams ensures that train drivers have all the necessary skills and knowledge to perform their jobs safely and efficiently, which is of utmost importance to the entire railway system.Wanting to raise the level of knowledge, skills, and training of train drivers who have mastered the Program and those who have little experience, some companies introduce a simulator into the training of candidates as the most modern tool that will enable raising the level of knowledge and training of train drivers. During the preparation for taking the professional exam, the candidates will have the opportunity to see the application of theoretical knowledge on the simulator, which allows the candidate to see it as a real train ride.

2. METHOD OF TAKING THE PROFESSIONAL EXAM FOR THE TRAIN DRIVERS

The professional exam is determined by the Rulebook on professional training, professional qualification and professional exam. The professional exam is taken before the first independent performance of the driver's duties after employment. The professional exam for the position of driver consists of a theoretical and a practical part. For passing the professional exam, the preparation for taking the professional exam is also determined by the Rulebook on professional training, professional qualifications and professional exam. In order for the employee, sent to take the professional exam, to continue with the program and to be sent to work under supervision, the candidate for train driver first takes the theoretical part of the exam according to the program for taking the professional exam. The theoretical part of the exam is taken after the theoretical training. In the theoretical part of the exam, the employee must demonstrate theoretical knowledge for the duties of a train driver and the tasks of that workplace, and in the practical part, the employee must demonstrate the skills to apply theoretical knowledge in practice in such a way that he can independently perform the duties of a train driver. The theoretical part of the exam is conducted by the employee verbally giving answers to the questions. The practical part of the exam is taken after passing the theoretical part and performing work under the supervision of another train driver for 14 weeks. The test of skills and abilities is evaluated through the jobs and tasks that the candidate demonstrates during the exam while performing the tasks as a train driver.

3. EXPERIENCE OF THE PROGRAM FOR TAKING THE PROFESSIONAL EXAM FOR THE POSITUION OF TRAIN DRIVER

The current way of taking the professional exam for train drivers includes theoretical part that includes theoritical knowledge and practical part where candidates apply their skills and knowlegde in operating the train under real conditions.The program is very specific and precise in terms of requirements and procedures, which helps create a standardized approach to driver training. Although the program is theoretically comprehensive, there is a possibility that the candidate will not be able to apply all the acquired knowledge in practice due to the lack of real situations.Here it is important to draw attention to the following. Many candidates will not experience all the critical situations during the expected 14 weeks of supervised work. Therefore, it is necessary to supplement the practical training with simulator training, as this will provide the necessary experience in rare but very dangerous situations for the safety of the train.

The need to add to the program for passing the professional exam for the position of driver by introducing training on simulators

Introduction of additional training on simulators in the training of train drivers, advantages and importance.

Learning simulators have become an indispensable part of train driver education, offering numerous advantages that complement and improve traditional training methods. Several key arguments that confirm the usefulness of simulators in this area:

Realistic experience: Simulators provide a realistic environment that mimics train driving, including visual and auditory elements, haptic feedback and simulation of different driving scenarios. This allows train drivers to gain experience in operating a train in a safe environment, without the risk of accidents or injuries.

Controlled environment: Simulators allow control over all aspects of the environment, including weather conditions, traffic situations and technical failures. It gives instructors the opportunity to challenge drivers in a controlled environment that helps them develop decision-making and problem-solving skills in real-world situations.

Repetition of exercises: Simulators allow train drivers to repeat exercises and scenarios as many times as they want, without additional costs or time constraints. This helps them to improve their skills and build confidence in operating a train in all conditions

Cost savings: Simulators are significantly cheaper to use than training on real rails. Savings are achieved through lower fuel costs, wear and tear of rolling stock and infrastructure maintenance.

Safety: Simulators eliminate the risks of accidents and injuries that are inherent in training on real rails. This results in safer and more efficient train driver education.

Environmental sustainability: Simulators are a more environmentally friendly alternative to training on real rails, because they do not produce noise, air pollution and consume less fuel.

Training for specific situations: Simulators can be used to train drivers to operate specific types of trains, drive on specific lines or face specific challenges. This helps prepare drivers to work in real-world scenarios.

Development of soft skills: Simulators can be used to train drivers in soft skills such as teamwork, communication and decision-making under stress. This helps them become better and more efficient drivers.

Adaptability: Simulators can be adapted to the individual needs and abilities of the driver, which makes them ideal for education at all levels of experience.

Availability: Simulators have become increasingly available and inexpensive, making them a more accessible option for educational institutions and railway companies.

4. CONCLUSION

The introduction of simulators in the program for taking the professional exam for train drivers represents a significant improvement in training, enabling more efficient, safer, and more economical preparation of candidates.Although there are implementation and maintenance challenges, the benefits of simulators in terms of training quality and safety significantly outweigh these obstacles.Train drivers who have started to drive independently are expected to prioritize safety over efficiency.However, proper and efficient driver handling is critical to safety when it comes to and life and infrastructure, time efficiency and economy.Even a small difference in expertise can make a big difference in terms of increased risk. It can therefore be argued that candidate training with simulator training should ensure that most of the potentially critical situations that may occur should be practically trained until candidates have mastered them. Simulator training can be used as a supplement to internships to ensure that train drivers can handle a variety of situations and special cases that rarely occur in real life.

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KPIs FOR EVALUATING THE NEW TECHNOLOGIES EFFICIENCY: THE CASE OF ZRS A.D. DOBOJ

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Abstract – *European freight railway operators, aiming to remain competitive in the Single European Railway Area, cannot enhance their competitiveness relative to road transport or meet user demands without investing in new technologies. The efficiency brought by these new technologies is a current and relevant topic (state of the art), but it must be verifiable and measurable. This is particularly important for railway operators on small networks, such as Republika Srpska Railways JSC. (Serbian: Zeljeznice Republike Srpske A.D. - ZRS), which have limited resources for investment. Therefore, it is crucial to identify and implement new technologies that will yield the greatest effect, thereby improving the competitiveness of the operators in the open market. The primary goal of this paper is to quantify the effects of introducing specific new technologies on the competitiveness of ZRS. The competitiveness of freight rail services is evaluated from the perspective of users (end users, freight forwarders, and logistics companies). By developing a set of KPIs for ZRS as a freight railway operator, it is possible to measure the direct impact of new technologies and technical solutions on the competitiveness of ZRS's rail services, thereby addressing identified weaknesses.*

Keywords – freight railway operator, performance indicators, efficiency, new technologies, competitiveness.

1. INTRODUCTION

The introduction of new technologies, digitization, and automation creates conditions for providing more efficient, reliable, and higher-quality transport services [1]. European railway operators, if they want to remain competitive in the Single European Railway Area, cannot enhance their competitiveness without investing in new technologies. The efficiency brought by new technologies is a current and relevant topic (state of the art), but to invest in new technologies, it is necessary to answer the question of which new technologies to implement. The selected solutions must be verifiable and measurable.

The comprehensive goals of European policy for establishing an internal railway market and strengthen the competitiveness and attractiveness of railway operators, while maintaining the position of the European railway industry, will inevitably result in the emergence of innovative approaches and the application of new technologies in business models, services, and products throughout the entire rail transport chain [2]. This would undoubtedly necessitate a significant rise in research and innovation efforts in freight transport operations.

The role of railways in global transport could and must be increased, primarily in the area related to leveraging the advantages of digital technologies to ensure that rail services are well integrated into a range of mobility options available to transport service users. Therefore, it is important to understand the new technologies that will produce the greatest effects, i.e., improve competitiveness in the freight railway market. This is particularly important for small operators like Republika Srpska Railways (ZRS), which have limited resources for investment, to take advantage of certain grants from various EU funds and prepare and improve its operator's business for market competitiveness.

Over the following decade, three main areas have been designated as the primary areas for railway and transport industry enhancements: vehicles, signaling, and after-sales services. Each of the three components can be analyzed independently from the viewpoints of companies (operators and infrastructure managers) and service users.

Bearing in mind above mention the question that the future national ZRS freight railway operator face on is :which new technologies, as researched through literature and

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supported by EU funds, could be applied and utilized to improve competitiveness? An answer to the abovementioned question is provided by the establishment of a set of key performance indicators (KPIs) to evaluate the contribution of new technologies to increasing competitiveness.

This paper first identifies certain weaknesses of ZRS freight railway services compared to competitors from the perspective of users (end users, freight forwarders, and logistics companies). New technologies used by freight operators, which ZRS could implement to increase its competitiveness and eliminate identified weaknesses in railway services are presented. A set of key performance indicators (KPIs) is defined for evaluation of the impact of new technologies on improving ZRS's competitiveness.

2. WEAKNESSES OF RAILWAY SERVICES AT ZRS A.D. DOBOJ

ZRS A.D. Doboj is a joint-stock company that is currently in the process of restructuring and has not yet experienced market liberalization. Therefore, the quality of service has remained consistent, and there is no competition in freight transport on ZRS infrastructure. Nevertheless, road carriers are ZRS's primary competitors in the global market, and the quality of service that freight forwarders and customers anticipate in terms of digitization and door-to-door service delivery is becoming more rigorous.

From the perspective of freight forwarders and transport service users, the following are the weaknesses of ZRS freight railway services that require development in order to increase the operator's competitiveness:

Transport service costs – As transport costs include all expenses incurred during the provision of transport services (electricity or diesel fuel costs, labor costs, maintenance costs, auxiliary service costs, etc.), it is necessary to do everything possible to rationalize these costs to ultimately achieve competitive transport prices in the market.

Transport time – The transport time in rail traffic depends on many factors (line speed, border crossing delays, marshalling yard delays, initial and final operations delays, wagon turnaround time, etc.). The goal is to achieve the shortest possible transport time, thereby increasing the competitiveness of the railway operator.

Availability of information on transport and goods – This includes the availability of information on train movement, wagon status, infrastructure load, tracking of goods being transported, transport disruptions, travel time delays, transport reliability, the percentage of realized paths, etc. For users, it is crucial to have timely information on the status of trains, wagons, or containers during transport (to enable timely response and create competitive advantages over other freight transport competitors).

3. NEW TECHNOLOGIES FOR FREIGHT TRANSPORT ON RAILWAYS

A variety of contemporary technologies are implemented in the global railway freight transport industry to enhance the competitiveness of operators.

The new technologies elaborated further in this paper are presented in the context of contributing to overcoming the identified weaknesses in ZRS transport services.

3.1. New technology for eliminating weaknesses - Transport service costs

A wide range of wagon types run on railways, the technical state of which is largely determined by the railway administrations where they are included in the fleet and the method of maintenance. ZRS and Eastern European railways are distinguished by relatively old wagons and inadequate maintenance, reducing rail freight movement to a period of limited effectiveness. . By including an obsolete maintenance workshops and a technical delay in comparison to advanced railways, a comprehensive understanding of the factors that greatly impact the costs of transport services is gradually achieved.

Cavuto et al. (2016) note that most wagon defects can be detected under dynamic conditions [4]. That is, it is necessary to monitor the condition of individual parts and assemblies of wagons even during operation. The development of electronics, sensors, and computer technology enables the introduction of onboard diagnostics in wagons and trains.

The continuous monitoring of railway wagons and the efficiency of maintenance and propulsion energy consumption are substantially enhanced by modern diagnostic systems [5]. Recorded measurement data are stored and systematized, and decisions are made to implement specific activities that are designed to reduce maintenance costs and enhance vehicle efficiency, thereby rationalizing overall transport costs.

3.2. New technology for eliminating weaknesses – Transport time

Radio Frequency Identification (RFID) technology is a type of automatic identification system that is employed in transport systems to generate, consolidate, and accelerate information processing, as well as to increase accuracy and automate data processing [6].

Tracking the dispatch of trains and goods within the railway system is essential for optimizing operational efficiency. Positioning and identifying trains with high precision in any environment is made possible by RFID technology. RFID equipment is employed to identify an ID tag affixed to a train or wagon in order to determine the precise moment at which the train passed a specific location in the context of the train location. On a railway sleeper, the reader is situated between the rails or along the track [7]. The track is typically equipped with a system that has the reader positioned along the side to identify each passenger coach or freight wagon that passes by [8]. Through the installation of tags on trains and wagons, as well as their readers in stations and on the track, the digitization and transmission of information regarding the status of the wagons and trains on the track are facilitated digitally and directly into the system.

The operator can optimize the transport process and time by facilitating the monitoring of wagons or products being transported through the availability of real-time information regarding the movement of trains and wagons on the track network.

3.3. New technology for eliminating weaknesses - Availability of information on transport and goods, as well as transport time

The utilization of electronic consignment notes, which are derived from Electronic Data Interchange (EDI) technology, is becoming more prevalent in international freight transport. This results in increased operator competitiveness in the transport market, speedier data transfer, data processing efficiency, and data accuracy, in addition to time savings. The exchange of standard business documents in a predefined format between the computer applications of business counterparties via computer networks is a component of EDI [9].

The electronic consignment note is implemented in railways through the utilization of software designed for electronic consignment notes, as well as the connection to European information systems and services such as "Orpheus," which facilitates the transfer of electronic consignment notes between countries that are structured in accordance with a widely accepted and widely implemented html standard. Information regarding products transported by rail to the ZRS network or other countries is immediately accessible to ZRS and, subsequently, to users through the utilization of these digital systems.

Finally, the gradual harmonization of technical, administrative, and regulatory rules is essential if railway transport is to achieve competitiveness and increase its share in the transport market.

4. KPIs FOR EVALUATION THE EFFECTIVENESS OF NEW TECHNOLOGIES ON COMPETITIVENESS

To quantify the impact of the abovementioned new technologies and technical solutions on ZRS and simultaneously contribute to achievement of the primary objective such as enhancing the competitiveness of railway operators in the market, it is imperative to establish key performance indicators (KPIs). From the perspective of service users, three characteristics of transport services are key for pursuit the overarching objective of enhancing competitiveness. Consequently, KPIs are organized in accordance with these characteristics.

The defined individual KPIs, which allow for measuring the impact of selected new technologies on overcoming the weaknesses of freight transport services and consequently on improving competitiveness, are presented in Table 1.

Tab. 1. KPIs for assessing new technologies and improving the competitiveness of freight transport services

KPI	Description	Unit
TRANSPORT SERVICE COSTS		
Specific transport costs	Transport costs for the customer in euros per train kilometer and unit	EUR/ km/unit
Operational costs	Operational costs include energy consumption, traction costs, maintenance, and repair costs	EUR
Productive use	Represents the annual km of a wagon or locomotive. The higher the effective km, the lower the impact of investment costs	km
Administrative costs	Personnel costs, forms, licenses, permits, etc.	EUR
Level of staff expertise and training costs	Specific skills are required for the implementation of new technologies – training costs	EUR
TRANSPORT TIME		
Delivery time	Time elapsed from the moment the transport order is placed to the arrival and receipt of goods (includes loading/unloading times, waiting times, train configration times, etc.)	h
Loading/unloading	Average and maximum time necessary to load/unload a wagons or trains in the terminal or an end point	h
Idle time	Average and maximum idle time (or exceeded idle time): - waiting at the terminal; - waiting for departure; - waiting for transshipment at the port; - waiting for equipment (engine), etc.	h
Train configuration time	Average and maximum time necessary to get wagons coupled to form a train	h
AVAILABILITY OF INFORMATION ON TRANSPORT AND GOODS		
Visibility	Infrastructure visibility: - Volume of network information; Visibility of service: - % of freight for which information in transit is available; - % of km for which information in transit is available; - Number or % of partners who provide data. Tracking and tracing: - Availability of precise tracking; - Availability of tracing; Disruption visibility: - Availability of information in case of disturbances; - Idle time between arising an event and getting inform;	%
Reliability	% of transport meeting the scheduled and promised time	%
Technical reliability	- Delays on the railway network, locomotive, wagons; - Train path availability (% of successfully vs. rejections); - Time deviation of the demanded train path (demanded vs. assigned).	%, h

Operational costs, for example, are one of the numerous indicators that demonstrate the freight transport operator's capacity to address the identified weaknesses from the perspective of transport service users, thereby improving its overall competitiveness. The significance of economically advantageous, timely, and swift delivery of goods to users is undeniable. As a result, any new technology that reduces the overall costs of vehicle maintenance also reduces the total transport costs, thereby enhancing the operator's competitiveness.

5. INSTEAD OF A CONCLUSION

Modern freight transport operators require technological advancements in all aspects of their operations in order to endure and enhance their operations. In light of the restricted resources and capabilities available for investment, it is imperative to exercise caution when selecting innovations. It is essential to evaluate which new technology is most effective in reducing the weaknesses of transport services, particularly from the perspective of transport service users, and, in the end, contributing the most to the overarching objective of enhancing the operator's competitiveness, given the current wide range of modern and new technologies being implemented in the railway sector.

The main focus of research on transport service weaknesses and the analysis of new technologies for operators is not to establish key performance indicators (KPIs) for the purpose of enhancing operational processes, but rather to evaluate the direct impact of new technologies and technical solutions on their efficiency and competitiveness.

Particularly for small railway operators with restricted innovation capabilities, the establishment of critical key performance indicators (KPIs) is of utmost importance. By using key performance indicators (KPIs), it will be possible to evaluate the results of the implementation of new technology more efficiently and make decision-making faster.

This paper has identified the weaknesses of transport services that are essential for the overall objective of competitiveness, as well as the key performance indicators (KPIs) with a total of 12, which evaluate the impact of new technology on the competitiveness of ZRS. The quantification of key performance indicators (KPIs) for the final set of new technologies and a more comprehensive analysis of transport service weaknesses are potential future research directions for small freight railway operators.

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IMPLEMENTATION OF THE NEW INFORMATION SYSTEM FOR FINANCIAL MANAGEMENT (ERP SYSTEM) AT ŽRS A.D. DOBOJ

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Abstract – *It has been observed that most business processes and activities at ŽRS are based on paper documentation or are only partially automated. With a view to eliminating the existing shortcomings, it has been proposed that the new information system should be one from a group of modern ERP systems (Enterprise Resource Planning System) which, with their functionalities, enable the connection of business processes and organizational units that execute those processes into a single system. The advanced capabilities of modern ERP systems enable support for the business processes of individual companies - members of the holding, but also of the holding as a whole. ERP systems are modularly designed, with each module supporting a group of related business functions. The implementation of the ERP system brings numerous benefits, the most significant of which are: integration, standardization, optimization and automation of business processes, increased efficiency, recording of changes in real time, single input and single database. The implementation of the ERP system brings major changes: existing software solutions are abandoned and new ones are introduced, there is a change/redesign of existing business processes and the methods the organization functions as a whole.*

Keywords – information system, ERP system, implementation at ŽRS a.d. Doboj.

1. INTRODUCTION

Two approaches are possible when acquiring and developing an information system: the traditional approach (“on-premise"), which implies local implementation of software on equipment that is owned and located at the company's location, and the cloud computing approach ("cloud") in which the system is located at a remote location (very often outside the country's borders), on the supplier's equipment and is accessed via an Internet browser or specialized client software. Our analysis of the estimated implementation costs shows that the traditional approach has the advantage. Also, it is a fact that even after the reorganization from a single company to a holding structure, the majority owner of the capital of the RS Railways will be the Government of Republika Srpska, and the provisions of the Regulation on information security measures for state-owned companies prevent the complete implementation of an information system for financial management using "cloud computing" technology.

Based on the analysis of business processes and the adopted future organizational structure of RS Railways, which will be implemented in the form of a holding within which four companies will exist, it was proposed to introduce an integrated information system that would consist of the following modules:

- General ledger.
- Accounts receivable accounting.
- Liability accounting.
- Fixed assets accounting.
- Capital investment management.
- Sales management.
- Procurement and inventory management.
- Cost and income management.
- Management of receivables and payables upon maturity.
- Management of personnel records.
- Salary calculation.

The implementation of a module that meets these

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requirements would replace the majority of existing software solutions that are outdated and unintegrated, eliminate the need for multiple entries of the same data in different applications, reduce the number of records that are kept only in paper form, and improve business processes, automation of data processing, quality of planning, control and reporting.

2. TECHNICAL SPECIFICATION OF THE SOFTWARE SYSTEM ERP

The objective of introducing a new organizational structure is, in addition to compliance with the requirements of the European Union that regulate the field of rail transport, the establishment of RS Railways as an efficient and sustainable market-oriented business entity [1].

The new organizational structure is based on the following key principles that are valid for all legal entities within the future holding organization of the RS Railways:

- Market orientation.
- Customer orientation.
- Profit orientation.
- Executive responsibility and comprehensive responsibility.
- Horizontal hierarchies.
- Transparency in decision-making processes [2].

The implementation of the new information system for financial management should be implemented in the new organizational structure of RS Railways. However, its establishment is not a simple process, and for this reason, the transition to a new organizational structure - holding, through two phases, was proposed:

- Preparatory phase - which should last 12 months, i.e. it would ideally start 12 months before the establishment of the new organizational structure. The goal of the preparatory phase is to present the new structure to all employees and psychologically prepare them for the new structure so that their "transition" to the new holding organization will be successful.
- The transition phase - which begins with the official order of introduction of the new structure and will last an additional 12 months.

3. SOFTWARE LICENSES

In the process of acquiring a new information system for financial management, it is necessary to request:

- An application package of ERP solutions that supports business processes that take place in RS Railways and that fulfill all required functionalities for 140 users.
- The application package of ERP solutions should enable the calculation of wages for 2,100 employees (total for 4 companies).
- Licenses for system administration – for four users.
- Database software license.
- Integration Software License.

Regarding the right of use (license), the offered information system should enable the creation of users of different levels of access, namely:

- User with full access – has access to all system functionalities.
- A user with limited access – has the ability to view all data, but limited data input and modification capabilities.

Along with the offered software, it is necessary to submit the manufacturer's technical documentation. It should contain all the necessary data for access, management and maintenance of the system (technical description of the configuration, database, process, interface, maintenance instructions, etc.).

The bidder is obliged to submit the Form of technical characteristics for the hardware platform for all hardware and infrastructure that is necessary for the operation of the ERP solution according to the methodology of the software manufacturer. This includes defining the environment (development, test and production) according to the methodology, defining the specification and number of servers, client workstations and all necessary interconnections between servers, storage systems, backups and connections to the LAN network. This information is needed so that the RS Railways can decide whether the existing hardware resources are sufficient or need to be increased [3].

4. FUNCTIONAL REQUIREMENTS OF THE NEW INFORMATION SYSTEM FOR FINANCIAL MANAGEMENT IN RS RAILWAYS

The new financial management information system of RS Railways should be one of the modern ERP business systems (Enterprise Resource Planning System). Such business-information systems enable the connection of various business processes and organizational units that execute those processes into a single system. This leads to consistent operation of all sectors of the company - sales, procurement, storage, distribution, finance and accounting. Since in one business organization (especially a large one) there can be a very large number of business processes that intertwine with each other and often cross functional or organizational boundaries, the conclusion is that they are difficult to monitor and analyze [3].

In that case, the ERP system, as a unique information system, has a very important role because with its integration and various functionalities, it can significantly facilitate the management of the organization. This feature of the ERP system is particularly important in the light of the future organizational structure of RS Railways holding. The implementation of the ERP system should enable process management and provide information for making business decisions both at the level of future companies that will be established and at the level of the holding as a whole.

One of the basic characteristics of modern ERP systems is that they are predefined software solutions to support business processes that are based on the best world experiences and practices. Also, ERP systems of the newer generation are significantly flexible and their functionalities can be adapted to the specific needs of each organization. In this way, the implementation of the ERP system leads to the improvement of the existing business processes in the organization, increases the efficiency of the organization and ensures the optimal use of resources.

Before the emergence of the ERP system in the nineties of the 20th century, individual business functions were supported by individual software applications that were more or less connected, while the ERP system implies the complete integration of those applications into a single information system for business support.

Today, ERP systems are implemented in a large number of companies, especially large ones, and the key advantages of using these systems are:

- Integration of business processes.
- Standardization and optimization of business processes.
- Increasing efficiency.
- Improvement of work performance and productivity level.
- Recording of business changes in real time.
- High level of automation in data processing and reduction of errors.
- Unique data entry.
- Unique database.
- The possibility of creating quality reports for the needs of the Administration.
- Improvement and facilitation of the planning and control process.
- Increased security.
- Improving service and ultimate customer/client satisfaction.

Modern ERP systems consist of several modules or subsystems, each of which is intended for one group of business functions. How many ERP system modules will be installed in a certain company depends on its size, the type of activity it performs, the number of employees and other factors, but the following modules and their functionalities are common for ERP systems since they reflect the basic business functions common to most business entities: procurement and warehousing, sales management, finance and accounting, asset management, human resources.

Based on the analysis of the business processes taking place in RS Railways and the future organizational structure-holding, we conclude that RS Railways needs the introduction of an integrated information system that would consist of the following mutually integrated modules:

- General ledger.
- Accounts receivable accounting.
- Liability accounting.
- Fixed assets accounting.
- Capital investment management.
- Sales management.
- Procurement and inventory management.
- Cost and income management.
- Management of receivables and payables upon maturity.
- Management of personnel records.
- Salary calculation.

The successful implementation of the above-mentioned modules would significantly improve the existing IT environment in RS Railways and, as a result, eliminate the observed shortcomings:

- Use of outdated and non-integrated applications.
- Weak support of business processes by applications in use.
- Multiple entry of the same data in different applications.
- Lack of automatic data processing and control.
- Out-of-date reporting.
- A large number of records exclusively in paper form.

5. RISKS AND ASSUMPTIONS OF THE IMPLEMENTATION OF THE NEW INFORMATION SYSTEM IN RS RAILWAYS

The implementation of a new information system is, as a rule, a complex, long-term and extensive project, associated with many risks. Practice has shown that these are expensive projects that have a significant failure rate (consulting company Gartner made an assessment in 2017 that showed that even up to 75% of all ERP system implementations do not achieve all the set goals). The implementation of a new information system brings big changes - in addition to abandoning the existing software solution and introducing a new one, there is also a change/redesign of existing business processes and a change in the way the organization functions as a whole [3].

The process of implementing a new information system represents a project of strategic importance for the company, during which its stakeholders face a large number of different problems, from the technical and organizational aspects. In order to avoid bad practices and common mistakes, it is very important to identify implementation risks and adequately address them.

The identification of implementation risks and measures to mitigate them becomes particularly important when it is taken into account that the implementation is being carried out in the conditions of the entire restructuring of RS Railways, which in itself represents a significant aggravating circumstance for successful implementation.

The main technical risks of implementation are:

- Adequacy of the selected information system.
- Complexity of information system implementation and maintenance.
- Inadequate data migration.
- Technological unpreparedness of the organization.
- Inadequate integration with other applications / subsystems in use.

The basic measure for mitigating the technical risks of implementation is clearly and precisely defined hardware and functional requirements that the information system must satisfy in order to fully support business processes, and based on such defined requirements, the selection of the optimal software solution.

6. CONCLUSION

The new financial management information system of RS Railways should be one of the modern ERP business systems (Enterprise Resource Planning System). Such business-information systems enable the connection of various business processes and organizational units that execute those processes into a single system. This leads to consistent operation of all sectors of the company - sales, procurement, storage, distribution, finance and accounting. Since in one business organization (especially a large one) there can be a very large number of business processes that intertwine with each other and often cross functional or organizational boundaries, the conclusion is that it is difficult to monitor and analyze them.

In that case, the ERP system, as a unique information system, has a very important role because with its integration and various functionalities, it can significantly facilitate the management of the organization. This feature of the ERP system is particularly important in the light of the future organizational structure of RS Railways - holding. The implementation of the ERP system should enable process management and provide information for making business decisions both at the level of future companies that will be established and at the level of the holding as a whole.

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The process of implementing a new information system represents a project of strategic importance for the company, during which its stakeholders face a large number of different problems, from the technical and organizational aspects. In order to avoid bad practices and common mistakes, it is very important to identify implementation risks and adequately address them.

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RAILWAY PROJECT MANAGEMENT – CONTEMPORARY ISSUES AND SOLUTIONS

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Abstract – *Railway transport is essential for the economic development of countries. However, railway project management faces a number of challenges. This scientific article analyzes the current problems and proposes solutions for the optimization of railway transport. The article examines the European policy for the development of railway transport and the role of the state in the construction, management and rehabilitation of the railway infrastructure. An overview of the possibilities for financing railway projects through funds from the state budget and funds from the European Union is presented. The article provides analysis and suggestions for improving the management of railway projects and achieving a more efficient and sustainable railway transport.*

Keywords – railway projects, project management, railway infrastructure.

1. INTRODUCTION

Modern EU directions for the development and planning of transport infrastructure are aimed at the search for environmentally friendly transport. Rail transport is a favorite in this direction, although it is a serious consumer of electricity and is a noise pollutant.

According to the revised EU regulation on the development of the trans – European transport network TEN-T, a high-speed, continuous and reliable transport network must be built on the territory of Europe to serve the increased traffic. In [1] presents the Commission's latest guidelines for the development of the TEN-T network at three levels. The deadlines are:

- 2030 – core network;
- 2040 – interim deadline for an extended transport network;
- 2050 – a comprehensive network.

Building a comprehensive TEN-T network will provide better and faster connections for passengers and freight, better connectivity between different types of transport infrastructure. The priority areas for building the TEN-T are:

- Three-stage deployment of the European Rail Traffic Management System (ERTMS);
- Switching to a European standard track gauge;
- Increasing the number of freight trains with a length of 740 meters in order to increase the capacity of the transported goods and the efficient use of transport infrastructure;
- Minimum speed 140 km/h for passenger trains;
- Better connectivity between rail transport and multi-modal terminals, airports, ports, etc.

One of the important problems of the TEN-T network is the unification of schedules, maintenance services and cleaning of trains.

The processes of booking and buying tickets online should be carried out through as many distribution channels as possible and have an improved user experience as in flights.

The achievement of environmentally friendly, safe and sustainable rail transport is through projects financed by European funds or by individual countries.

2. CONTEMPORARY PROBLEMS IN THE MANAGEMENT OF RAILWAY PROJECTS

The management of railway projects is essential for the successful planning, implementation and operation of railway infrastructure. Railway projects are expensive undertakings, which necessitates effective management of various costs.

For the implementation of successful transport projects, close cooperation between the government and various stakeholders is needed, paying special attention to environmental aspects. Projects that enjoy broad public support are more likely to be implemented successfully [2].

The main problems in the management of railway projects are:

- Compliance with deadlines;
- Completion within the budget;
- Risk management;
- Management of subcontractors;
- Management of the supply of equipment and materials;
- The quality of the work on the project;

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- Environmental impact management.

Modern trends in railway project management are aimed at improving efficiency, reducing costs and minimizing risks. Rail project management focuses on designing and building sustainable railway systems that are environmentally friendly and energy-efficient.

Railway projects are exposed to various risks, such as natural disasters, technical problems and human error. Modern risk management methods help to identify, assess and mitigate potential risks.

The implementation of mobile and cloud technologies, 3D modeling, big data analysis increases the ability to collaborate in real time and improve the processes of railway project management. 3D models of railway projects are used to simulate construction processes and identify potential problems before they arise. Big data can be used to collect and analyze information about railway projects, such as traffic data, maintenance models, and performance data. This information can be used to optimize operations, predict problems, and make better decisions.

Good management of railway projects leads to an increase in the efficiency of railway transport. It stimulates economic development, improves the quality of life and contributes to the achievement of sustainable transport.

Railway projects are necessary initiatives related to increasing transport connectivity between places, increasing safety, travel comfort, solving environmental problems, etc. They have varying degrees of complexity, no matter if they are short-term or long-term. Their implementation is associated with many risks that arise due to the long implementation period. Their implementation is accompanied by delays, budget overruns, large scope, high costs, unjustified expectations.

The main success factors of a project are: cost management, time management, communication management, risk management, project team and contractors [3].

Project management is aimed at managing the five elements of the extended project triangle: scope, time, budget, quality and risk. These five elements are at the heart of the project planning stage. The scope of the project has an impact on risk management. Identifying risks involves a literature review and interviews with entrepreneurs and is an ongoing process. Railway projects are accompanied by three groups of risks: global risks; internal risks and force majeure risks for the project. The risks may be related to the contractor, the consultant, etc. Each project should have a register of the current risks and the cost of such a problem [4].

An overview of the most used project management methods and approaches is described in [5], [6], [7]. Standard project management methods such as: critical path method, program review and evaluation, Gantt chart are also used in railway projects. A methodology for flexible management of railway projects has been proposed, to which artificial intelligence can be added [5].

A new project management methodology is described in [8], which estimates costs based on historical data at an early stage. An economic assessment of the project is being prepared. During the engineering design and implementation of the project, the budget can be adjusted. An unexpected increase in costs requires revision or additional funding.

3. USE OF ARTIFICIAL INTELLIGENCE IN RAILWAY PROJECT MANAGEMENT

Tang R and others, provides a comprehensive overview of current research focused on the application of AI in railway transport. Artificial intelligence is used in all phases of the project [9]:

- Adoption – identifying the opportunities for AI in the project.
- Initiation – development of an AI deployment plan,
- Planning – defining tasks and resources for AI.
- Product selection – choosing the right AI tool for the project.
- Implementation – integration of AI into the project.
- Monitoring – tracking AI performance
- Wrapping up – assessing the impact of AI and learning lessons.

It is important to note that AI is a powerful tool that can improve the efficiency of projects.

In transport project management, a huge amount of textual data is generated that can be analyzed to optimize processes, reduce costs, and increase efficiency. The analysis of text data is limited by the languages in which the data is collected. Currently, data is processed in English, Chinese, and French, which is a challenge for model developers.

In the future, we can expect more advanced AI applications for decision-making, optimization, dealing with uncertainty, and cyber threats.

4. CURRENT RAILWAY PROJECTS ON THE TERRITORY OF THE REPUBLIC OF BULGARIA

The implementation of the planned railway projects according to [10], [11] will bring benefits to society and the economy. With the development of new and modern infrastructure, railway transport will be much faster, safer and more competitive with other modes of transport. The transported cargo is expected to increase due to increased safety and reduced travel time. The environmental impact of transport is expected to be reduced and energy efficiency increased.

An overview of the current railway projects that are being implemented in the Republic of Bulgaria is presented in Table 1. They are funded by: the Connecting Europe Facility, the National Recovery and Resilience Plan and the Transport Connectivity Program 2021 – 2027.

Tab. 1. Current railway projects in the Republic of Bulgaria

№	Project Expected Completion	Funding	Expected completion
1	Modernization of the railway line Elin Pelin - Kostenets .	OPTTI/PTS	2028
2	Rehabilitation of the railway line Plovdiv - Burgas, phase 2.	OPTTI/PTS	2025
3	Rehabilitation, repair and modernization of ERSS (Electric Railway Sub-Station) Varna and Razgrad and construction of ERSS Ruse and introduction of the SCADA.	OPTTI/PTS	2025
4	Modernization of the railway section Sofia - Dragoman - the border with the Republic of Serbia: railway section Voluyak - Dragoman.	OPTTI/PTS	2027
5	Development of Sofia Railway Junction: Sofia - Voluyak Railway Section.	OPTTI/PTS	2025
6	Modernization of the railway section Sofia - Elin Pelin.	MCE	2024
7	Development of Plovdiv Railway Junction .	MCE	2025
8	Modernization of the railway section Kostenets - Septemvri.	MCE	2026

Effective selection of railway projects is essential to optimise investment and ensure the sustainability of railway transport. This process involves a comprehensive assessment of various factors to determine the projects with the highest return on investment and the greatest benefit to society. Methods such as: multi-criteria analysis, cost-benefit analysis, traffic modeling, etc. are used. [12].

Railway infrastructure projects are complex, focusing on modernization, rehabilitation, reconstruction and construction of new routes. These routes are part of the core TEN-T network. The speed for which the railway network must be adapted is 160 km/h, which requires all crossings to be replaced with underpasses or overpasses. The problems in the management of infrastructure projects are related to the occurrence of unforeseen activities and problems due to the crossing of power lines, gas pipelines, various categories of roads, waterways, the discovery of archaeological finds, etc.

5. CONCLUSION

The article presents the main problems and solutions in the management of railway projects. The identified problems in railway projects are related to the duration of the procedures for planning and implementation of projects. This requires search for new methods of project management, as well as easing the procedures for selecting a contractor, expropriating land, appeals, etc.

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The Graduates and the Future of Railway

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RESEARCH ON THE DYNAMICS OF RAILWAY VEHICLES USING THE SOFTWARE PACKAGE SIMPACK RAIL

Student: Ivica BUDROVAC [1]
Mentor: Milan BANIĆ [2] [0000-0001-8684-042X]

Abstract *– This thesis presents how modern software can be used to predict the behavior of railway vehicles and determine the dynamic quantities that affect vehicle safety and ride quality. The UIC-518 standard, which provides information on all regulations concerning on-track testing and the analysis of results regarding the approval of railway vehicles for use, was utilized to determine the dynamic quantities and their limit values. This standard defines four scenarios or test zones in which vehicle testing must be conducted, differing in track layout and vehicle speed. In addition to the dynamic quantities prescribed by UIC-518, this thesis will measure two additional quantities not required by the standard: the WZ ride comfort index and the wheel and rail wear coefficient. The simulation of the railway vehicle's movement was performed using the Simpack Rail software package, where a complete model of a passenger vehicle was created. The LHB wagon, used on Indian Railways, was taken as an example of a passenger vehicle. The track was designed according to European standards with a gauge width of 1435 mm and a rail inclination of 1:40. The second, third, and fourth scenarios include curve radii ranging from large radii over 2000 m to curve radii of 250 m, where the rail superelevation for each scenario is 100 mm. The speed was chosen arbitrarily but within the limits defined by the standard. Due to the lack of data, track irregularities, which significantly affect safety and ride quality, are not included in this study. At the end of the thesis, the results obtained from the simulation are compared with the limit values according to UIC-518.*

Keywords – dynamics of railway vehicles, UIC-518, WZ ride comfort, rail wear coefficient, Simpack Rail.

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WHEEL SLIDE PROTECTION IN RAILWAY VEHICLES BRAKING

Student: Lazar RANKIĆ [1]
Mentor: Dragan MILKOVIĆ [2][0000-0002-3739-4600]

Abstract *– The paper presents the results of master's thesis dealing with checking the brake performances of railway vehicles at different adhesion conditions and working principle of wheel slide protection systems. The braking system is a significant system responsible for safe service of railway transport. It must meet many requirements defined in different international standards. The main terms and definitions associated with wheel slide protection are presented and explained. This research focuses wheel slide protection and its role to ensure the smallest possible increase in stopping distance in conditions of low adhesion for vehicles with pneumatic brake system and for the KT4 tram as an electric type of vehicle. Several control algorithms for control of brake system performances and wheel slide protection are presented along with their input and output parameters and error evaluations. During research we used different measurement methods and techniques within on-track brake tests with the TVEMA track recording vehicle of "Serbian Railway Infrastructure" AD.*

Keywords – wheel slide protection, railway brakes, on-track tests.

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BIOMIMICRY AS A METHOD FOR AERODYNAMIC TRAIN DESIGN

Student: Pavle SAVIĆEVIĆ [1]
Mentor: Jovan TANASKOVIĆ [2] [0000-0002-2936-5535]

Abstract *– The aim of this thesis is to provide a broader picture that refers how to overcome one of the greatest and most challenging problem that will always remain relevant—solving the issue of aerodynamics in a traction rail vehicle, considering that air resistance accounts for 80% of the total traction resistance. The entire topic will be addressed through the design of trains inspired by nature, respecting its laws. We will return to that primordial view of the world, which provides answers to all questions. Biomimicry is the process of observing natural phenomena, flora, and fauna as models for sustainable design and engineering of various products and processes. In recent years, nature-inspired design has become a popular term. However, the idea is not new. Many technologies we use today are based on the principles of biomimicry. Biomimicry is no longer just a subject of study for scientists and academics. Many companies are now beginning to realize the potential benefits of biomimicry and are incorporating it into their business plans. One example of biomimicry in high-speed train design is replicating the shape of the kingfisher's beak to improve the aerodynamics of the train's front end. The long, aerodynamic beak of the kingfisher allows it to dive into water with minimal splash, thanks to its shape. By designing the front of the train to mimic the shape of the kingfisher's beak, engineers were able to reduce air resistance and noise, improving the overall performance of the train. This also solved the problem of the loud sonic boom that occurred when the train exited tunnels due to air pressure. Similarly, some engineers in Japan thought it would be interesting to apply the wing-folding mechanism of owls to improve the pantograph lowering mechanism, a device that draws electrical power from the overhead wires. Trains today move at extremely high speeds, constantly in the presence of the ground, nearby structures, and people, as well as passing through tunnels—all of which have always been challenges for aerodynamicists. Therefore, resorting to biomimicry as a method for aerodynamically designing trains has been characterized as a brilliant solution.*

Keywords – high-speed trains, biomimicry, aerodynamics, solutions.

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ANALYSIS AND OPTIMIZATION OF MAINTENANCE OPERATIONS EMU "FLIRT 413"

Student: Dušan PANTELIĆ [1]
Mentor: Jovan TANASKOVIĆ [2] [0000-0002-2936-5535]

Abstract *– The task of the master's thesis is the analysis of maintenance operations, such as the time required for the realization of regular inspections and extraordinary repairs. Analysis and normalization of operations aims to increase productivity in the maintenance process, which enables insight into deviations in the time required to perform some operations. Also, one of the tasks is to examine and consider the possibility of optimizing the maintenance process for certain activities, which have significant deviations compared to the times prescribed by the manufacturer. The collection of necessary data for the subject analysis shall be carried out by surveying respondents, employees of the company "SrbijaVoz a.d." and by directly measuring the time required for the implementation of certain operations, as well as detailed information regarding repairs. By analysis the measured times, from current cases, available resources and personnel, it could be concluded that some of simpler operations can be done in a shorter time, while some complex ones require more time. Further research in this area and the application of new maintenance technologies should contribute to the optimization of the maintenance process and the reduction of maintenance costs, while maintaining the required level of reliability and availability.*

Keywords – trams, maintenance, analyses, inspections.

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APPLICATION OF DEA METHOD IN RAILWAY TRANSPORT

Student: Marija JOSIMOVIC[1] [0009-0008-9956-0943]
Mentor: Nikola PETROVIC[2] [0000-0002-9166-1263]

Abstract *– The railway is a complex, dynamic system that constitutes the unity of railway infrastructure, vehicles, and personnel and has its function or goal. The main characteristics of rail transport are high speed, low cost, mass, and inelasticity. The main advantage of railways is their ability to transport large quantities of goods and people over long distances. From the moment of loading the goods or boarding passengers, the railway enables high-capacity transport at high speeds. One of the basic, but still insufficiently researched, performances is efficiency. In modern market operations, efficiency is a key factor in market success.*

Measuring efficiency is an important task of management to look at the previous operation of the unit and plan its future development. Considering the analysis model, the advantages of calculating the efficiency of the traffic solution can be applied in many other branches of the economy, such as education, various economic segments of city and state management, etc.

Efficiency can be defined as the ability to achieve desired goals with minimal utilization of available resources. Information about efficiency is relative to the analyzed data. So, different data give different efficiency, which, however, is only valid when applying the same model. On the one hand, the data obtained from practice (empirical data) are variable (daily, monthly, and annual unevenness is known) and can be influenced (accidentally or planned). On the other hand, from the point of view of mathematics, it is known that two opposite models give the same result, namely: smaller input and the same output (input model) or the same input and larger output (output model).

This research presents the application of the DEA (Data Envelopment Analysis) method for measuring the efficiency of rail freight transport in the Republic of Serbia from 2015 to 2021. In developing the DEA analysis model, the number of DMU decision units, or more precisely, variant solutions, is first determined, and each unit represents a specific year. The number of DMU decision units should equal or exceed the number of input-output parameters. The following parameters were used as input parameters: the number of employees in traffic and transport, the consumption of liquid fuels in traffic (in thousands of tons), the consumption of electricity in traffic (in thousands of MWh), the number of railway transport assets in the freight car fleet, and the and the tons of load capacity of railway transport assets expressed in thousands. As output parameters, the following were used: transported goods expressed in thousands of tons and transported goods in tons per kilometer. After certain DMU units, the number and sizes of input-output parameters have been determined, and the DEA model is set. The calculation was made based on the CCR model.

For 2017, 2018, 2019, and 2021, maximum efficiency was achieved. For the other observed years, 2015, 2016, and 2020, the percentage values for decreasing input and increasing output parameters are given.

Keywords – rail freight transport, efficiency, data envelopment analysis.

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U okviru 160ha na koliko se MIND Park prostire, za 5 godina, u skladu sa modelima industrije 4.0, izgrađeno je preko 60.000m2 najsavremenijeg proizvodnog i kancelarijskog prostora. Dom čak 19 svetskih kompanija, dok je njih 9 deo porodice MIND Grupacije.

AMM MANUFACTURING

AMM Manufacturing je specijalizovana kompanija za proizvodnju komponenti, poznata po visokokvalitetnim proizvodima i inovativnim rešenjima za šinsku industriju.

Dizajn i inženjering

- Pribor i alati za zavarivanje
- Transportne i logističke strukture

Proizvodnja - aluminijum i čelik

- Komponente karoserije
- Ubode i alati
- CNC obrada
- Zavarivanje
- Zavarivanje trenjem (FSV)

Adhezivno lepljenje

- Planiranje procesa i proizvodnja – nivo A1

Lakirnica

- Peskarenje
- Priprema i farbanje

IMW Institut

IMW Institut, smešten u MIND Parku, je posvećen naučno-istraživačkom radu i razvoju u tehničkim i tehnološkim oblastima. Institut se ističe svojim laboratorijama i odeljenjem za tehničku pripremu uzoraka. Njihove glavne aktivnosti uključuju testiranje zavarenih spojeva, metalnih materijala, vode, različitih industrijskih proizvoda i sirovina, kao i sadržaja metala u zemljištu.

1 MEHANIČKO-METALOGRAFSKA LABORATORIJA

- **Određivanje mehaničkih svojstava materijala**
- **Ispitivanje tvrdoće**
- **Ispitivanje udarne žilavosti**
- **Makrostrukturna analiza**
- **Mikrostrukturna analiza**

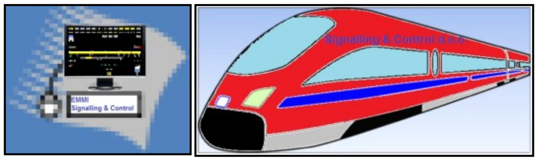
2 NDT LABORATORIJA

- **Ultrazvučno ispitivanje**
- **Vizuelno ispitivanje**
- **Ispitivanje tečnim penetrantima**
- **Ispitivanje magnetnim česticama**
- **Ispitivanje digitalnom radiografijom**

3 HEMIJSKA LABORATORIJA

- **Određivanje hemijskog sastava metala metodom OES**
- **Određivanje sadržaja metala iz rastvora metodom ICP/OES**


98 72 8 724 001-2
NIS
GAZPROM NEFT
SCHOMA
CFL-350 DV-R-5755
33 RIV
72 SRB-NIS
7989 031-9
Zaes-z



SIGNALLING & CONTROL

Company for Engineering " Signalling & Control" Ltd.
Branka Krsmanovića 20, 11000 Belgrade, Serbia

Quality Management System ISO 9001:2015 for the following scope of operation: **Design and development, assembly, installation, testing, maintenance, technical checking of design, technical examination and acceptance of signalling-safety, electronic and telecommunications systems with diagnostic software on railways.**


DENETIK CERTIFICATION ISO 9001

CERTIFICATE

This is to certify that organization:

Signalling & Control d.o.o.

Branka Krsmanovića 20, 11000 Belgrade, R. Serbia

has implemented and maintains an Quality Management System within the scope of:

Desing and development, assembly, installation, testing, maintenance, techical checking of desing, technical examination and acceptance of signalling-safety, electronic and telecommunications systems with diagnostic software on railways

in accordance to:

ISO 9001:2015

Certificate No.: SRN3522
Date of issue: 25.01.2024.
Expiry date: 02.02.2027.
Initial Certification date: 03.02.2012.

General Manager:

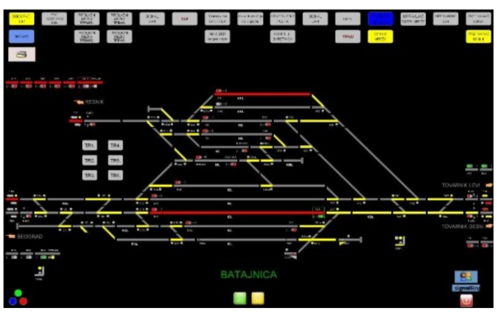
Licenses of the Ministry of civil, traffic and infrastructure of RS:

- **P141E4** - Projects of control, automation, measurements and regulation for public railway infrastructures with connections;
- **I141E3** - Realization of telecommunication networks and systems for public railway infrastructures with connections.

License of the Directorate of Railways of RS for maintenance of safety signalling equipment.

MAIN PRODUCTS:

EMMI - ELECTRONIC MAN MACHINE INTERFACE

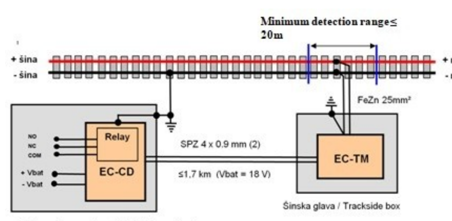


EI - ELECTRONIC INTERLOCKING (SIL4)

ELC - ELECTRONIC LEVEL CROSSING (SIL4)

EAC - ELECTRONIC AXLE COUNTER (SIL4) with rails continuity detection

ERC - ELECTRONIC RAIL CONTACT



Detector

Trackside Module

Trackside Box.

VARIOUS MODULES FOR SIGNALLING SYSTEMS

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Mob.: +381 63 397 249
E-mail: sigcon@verat.net
http://www.sig-con.com

FOKUS TECH

3D OBSTACLE DETECTION SYSTEMS

www.fokus.si