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Plenary Session

INFRASTRUCTURE CONDITIONS AND COMPLIANCE WITH TEN-T STANDARDS ON THE RAIL NETWORK ON THE WESTERN BALKAN

Dejan LASICA[1]
Kire DIMANOSKI[2]

Abstract *– TEN-T policy in the Western Balkans is a key factor in driving economic growth and bringing the region closer to the EU. The extension of the TEN-T in the Western Balkans has become an important instrument for external action by the EU, improving connections between regional markets and contributing to fostering peace, stability and prosperity. Infrastructure development, together with transport acquis transposition, are the two main pillars of the Transport Community. The Core Network should be fully compliant by 2030, the Comprehensive Network by 2050, and current compliance rates, as highlighted in this paper, show that the achievement of these targets is far from an easy task. The EU has committed a substantial financial package for the region, but there is still a considerable gap between needs and resources. In the previous 15 years, the region invested over 2 billion EUR in rail projects. However, conditions and quality of service were not increased. With an average operational speed of around 50 km/h in passenger transport, rail cannot compete with road transport. The situation is the same in freight, where significant time is spent on the preparation of trains, loading/unloading, and waiting time on the border. For these reasons, rail has lost a significant number of passengers and other business over the past 10 years. The two main reasons for such a situation are lack of proper maintenance and absence of reform. And these two aspects extend as the main causes throughout the paper. The paper ultimately will show that the completion of the TEN-T network requires firm political commitment and administrative effort. The infrastructure gap and limited funding call for more coherent and focused strategic planning. Apart from supporting mobility, TEN-T development is also a way to prepare for EU accession and ultimately improve citizens' lives.*

Keywords – TEN-T standards, Compliance, Infrastructure conditions, Maintenance

1. INTRODUCTION

TEN-T policy in the Western Balkans is a key factor in driving economic growth and bringing the region closer to the EU. The extension of TEN-T in the Western Balkans has become an important instrument for external action by the EU, improving connections between regional markets and contributing to fostering peace, stability and prosperity. Infrastructure development, together with transport acquis transposition, is one of the two pre conditions for the sustainability of the rail system on the Western Balkan.

Based on work undertaken under the SEETO framework and the establishment of the Transport Community, the indicative extension of TEN-T Comprehensive and Core network in the Western Balkans was made official through Commission Delegated Regulation (EU) 2016/758 of 4 February 2016 amending Regulation (EU) No 1315/2013 of the European Parliament and the Council for the Development of the Trans-European Transport Network. The indicative extension of TEN-T in Western Balkans includes:

- 5.287 km of TEN-T roads, out of which 3.540 km on the Core Network
- 3.898 km of TEN-T railways, of which 2.546 km on the Core Network
- 1.345 km of TEN-T Core Network Inland Waterways
- 3 seaports, 4 inland waterways ports, and 10 airports.

The Core Network should be fully compliant by 2030, the Comprehensive Network by 2050.

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Completing the TEN-T network requires firm political commitment and administrative effort. The infrastructure gap and limited funding call for more coherent and focused strategic planning. Apart from supporting mobility, TEN-T development is also a way to prepare for EU accession and ultimately improve citizens' lives. With it, rail network on the Western Balkan became attractive for the investors but also eligible for the pre accession instruments like WBIF fund or IPA.

2. NETWORK DESCRIPTION

TEN-T Rail Core/Comprehensive Network on the Western Balkan consists of lines presented in the following table:

Table 1. Description of the Indicative extension of the TEN-T Rail Core and Comprehensive Network to the Western Balkan

Corridor/ Routes	Comprehensive Network		Core Network	
	Nodes	Length (km)	Nodes	Length (km)
Corridor Vc	Bosanski Samac – Sarajevo– – Mostar Capljina (BIH)	428	Bosanski Samac (BIH) – Sarajevo– Mostar - Capljina (BIH)	428
Corridor VIII	Tirana/ Durres/ Vlore– Lin/Pogradec (ALB)- Kicevo– Skopje – Kumanovo – Beljakovci (MKD)	426	Tirana/ Durres/ Vore (ALB)	73
Corridor X	Sid (SRB) – Belgrade – Skopje (MKD) – Gevgelija/GR border	730	Sid (SRB) – Belgrade – Skopje (MKD) – Gevgelija/GR border	730
Corridor Xb	HU border/Kelebija – Novi Sad - Stara Pazova (SRB)	151	HU border/Kelebija – Novi Sad - Stara Pazova (SRB)	151
Corridor Xc	Nis (SRB)- Dimitovgrad/BG border	104	Nis (SRB)- Dimitovgrad/BG border	104
Corridor Xd	Veles (MKD) – Kremenica/GR border	145	-	-
Route 2	Podgorica (MNE) — Vore (ALB)	144	Podgorica (MNE) — Vore (ALB)	144
Route 4	RO border / Vrsac — Belgrade (SRB) — Bar (MNE)	580	RO border / Vrsac — Belgrade (SRB) — - Bar (MNE)	580
Route 7	Nis (SRB) – Doljevac (SRB) - Pristina (KOS)	152	-	-
Route 9A	Novi Grad (BIH) -Banja Luka– Doboj – Tuzla (BIH) – Brcko /Zvornik Loznica -Ruma (SRB)	491	-	-
Route 10	Lapovo- Kraljevo (SRB) — Pristina (Kosovo*) — Gorce Petrov (MKD)	340	Kraljevo (SRB) — Pristina (KOS) — Gorce Petrov (MKD)	254
Route 11	Pozega— Stalac (SRB)	138	Pozega— Stalac (SRB)	138
Route 13	HU border/ Horgos – Subotica (SRB)	28	-	-

(*) This designation is without prejudice to positions on status and is in line with UNSCR 1244 (1999) and the ICJ Opinion on the Kosovo declaration of independence.

The TEN-T rail network consists of two layers: Core and Comprehensive Network. The total length of the Comprehensive is 3,898 km but 3,572 km in operation. Length of the Core is 2,546 km with 2,437 km in operation. 326 km on the Comprehensive Network and 109 km on the Core Network is temporarily closed for safety reasons (lack of maintenance) or ongoing construction workstables, figures and program listings.

3. TEN-T CORE AND COMPREHENSIVE NETWORK COMPLIANCE

In the previous 15 years, the region invested over 2 billion EUR in rail projects. However, conditions and quality of service were not increased. With an average operational speed of around 50 km/h in passenger transport, rail cannot compete with road transport. The situation is the same in freight, where significant time is spent on the preparation of trains, loading/unloading, and waiting time on the border. For these reasons, rail has lost a significant number of passengers and other business over the past 10 years.

The two main reasons are: **lack of proper maintenance and absence of reform**.

Regarding the maintenance, latest study done by CONNECTA from 2018, explained that amount necessary for the regular maintenance is EUR 50.000 per km per year. However. No one from the regional partners have budget with more than EUR 18.000 per km per year. Another reason is slow reaction to all challenges on the market because of the lack of human resources in all segments from operational to the managerial positions. The current condition of the network was assessed based on data provided in the Western Balkan region on the current state of their tracks. To this purpose, conditions have been divided into five parts based on the ratio between current maximum operational speed and maximum designed speed on the network. This was done in order better to describe the current condition of the railway network.

Table 2. Assessment Methodology Criteria

Condition of railways	Condition of railways
Very good	0.86 – 1
Good	0.71 - 0.85
Medium	0.61 - 0.70
Poor	0.51 - 0.60
Very Poor	0 - 0.50

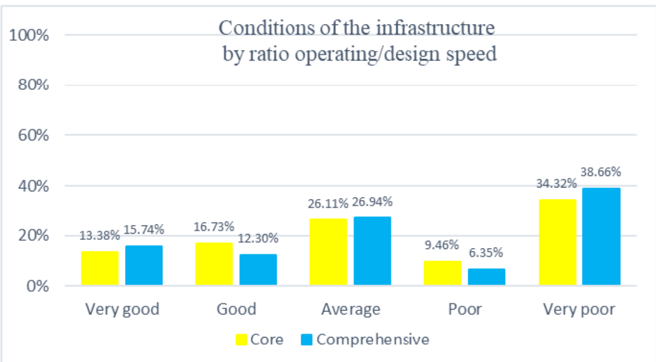

Fig. 1. Conditions of the railway infrastructure

As for the condition, 30% of the Core Rail Network and 28% of the Comprehensive is in very good and good condition, where approximately 70-100% of designed speed can be achieved. Approximately 26% of the sections is reported to be in average condition, with wide variations in the maximum allowed speed.

The greater part of the Core (44%) and Comprehensive Network (45%) is in poor or very poor condition, where the designed speed achieved averages only 50%. An important issue that should be mentioned is the reliability of the system for assessing the condition. On several sections, there was a large discrepancy between the reported condition, designed and maximum allowed speed. Furthermore, several different systems seem to be in use for assessing conditions in different Regional Partners.

3.1 Compliance with some TEN-T standards

This paper work covers assessment of the specific railway indicators as follows:

a) Electrification - rail network to be electrified by 2030 (including sidings where necessary);

b) Axle load: Freight lines 22.5 t axle load by 2030.

c) Line speed: Freight lines must allow 100 km/h by 2030 (no speed requirement for passenger lines);

d) Train length: Freight lines to allow for 740 m trains by 2030;

e) Track gauge: Nominal track gauge for new railway lines 1.435 mm;

f) ERTMS / signaling system: Core network to be equipped with ERTMS by 2030.

3.1.1 Electrification

Rail electrification compliance of the operational network is already 73% on the Core and 54% on the Comprehensive Network. Certain parts of the networks, mainly in Albania and North Macedonia (Corridor VIII), are still in the construction phase and are not part of this analysis.

Fig. 2. Map of electrified lines

3.1.2 Axle Load

For freight axle load, the compliance parameter of 22.5 t per axle is already at 87% on Core and 72% on Comprehensive Network as per 2021 data. The deficiencies are mainly in Albania, Kosovo* and Bosnia and Herzegovina.

3.1.3 Freight line speed

For freight line design speed, the 72% of the Core network is compliant with the parameter of 100 or more km/h as per 2021 data and 61% on the Comprehensive network. Related to the operational speed, only 15% of the operational Core network has an operational speed of more than 100 km/h and 13% of the Comprehensive Network. The deficiencies are mainly in Albania, Montenegro, Serbia, Kosovo* and Bosnia and Herzegovina.

3.1.4 Train length

For freight train length, none of the networks is compliant with the parameter of 740 m or longer sidings for trains. However, 79.5% of the Core Network and 73.4% of the Comprehensive can accommodate trains longer than 500 m. The region mainly meets the 500m parameter except in Albania. This, however, needs to be read with the above-mentioned caveats that the situation continues to improve and that there are differences here and there between nominal compliance and actual operational possibilities. For example, a line may be fit for 740 m trains but does not have enough sidings to turn that possibility into reality.

3.1.5 Track gauge

Rail track gauge is already compliant at a high 100% as per 2021 data. There is one notable exception in Serbia (the Mokra Gora narrow gauge rail line), but this is not part of the Core and Comprehensive Network and is only used for tourist purposes. The situation has been the same for many years and does not affect interoperability.

3.1.6 ERTMS

ERTMS operations started in the Western Balkan. For first time in history there is 2.72% of the Core and 2.39% of the Comprehensive network equipped with ERTMS system. This is because the newly reconstructed Belgrade – Novi Sad line started the operations. Almost all Regional Partners partly transposed the interoperability directive (third or fourth rail package). Looking at planned and ongoing projects, there are intentions to implement ETCS level 1 or even 2 in Albania, Kosovo*, Serbia and North Macedonia which will lead up to 52% of ERTMS system on the Core network.

ERTMS deployment is the greatest challenge in terms of TEN-T parameters, and progress is slower than anticipated or wished. However, all infrastructure managers in the region should make additional efforts in further transposition and implementation of the interoperability directive.

4. FORECAST 2027

Rail has been overshadowed by the road sector in overall investment for the past 15 years. While ca. 80% went on roads, the railway sector only received ca. 12% of total investment.

The situation has undergone a change, and the priority of railway transport has become a given. Nowadays, rail system improvement is an integral part of recently published strategic documents of the European Commission where priority is given to greener and more efficient transport modes such as the railway. Looking to the ongoing and finance secured projects in the region, there is estimation about forecast for the compliance with TEN-T standards in 2027. Overall, there is ten finance-secured or ongoing rail projects. The length of rail sections currently under various forms of upgrading is 877.8 km (all on the Core Network). Priority has been given to the Core Network. The projects' overall value is 3,687 billion EUR. All active projects have deadline for the completion 2027 or before. If all projects would be implemented successfully and without delay, conditions on the railway network will be improved as it is presented on the following graphs.

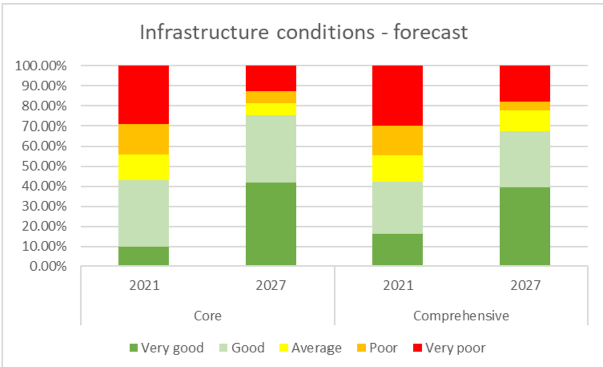

Fig.3. Infrastructure conditions – forecast 2027

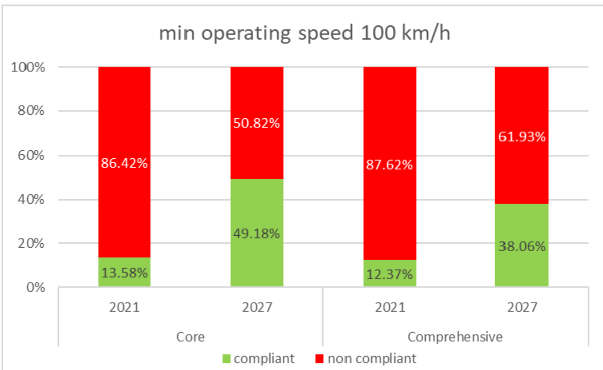

Fig. 4. Min operating speed - forecast 2027

* This designation is without prejudice to positions on status, and is in line with UNSCR 1244 (1999) and the ICJ Opinion on the Kosovo declaration of independence

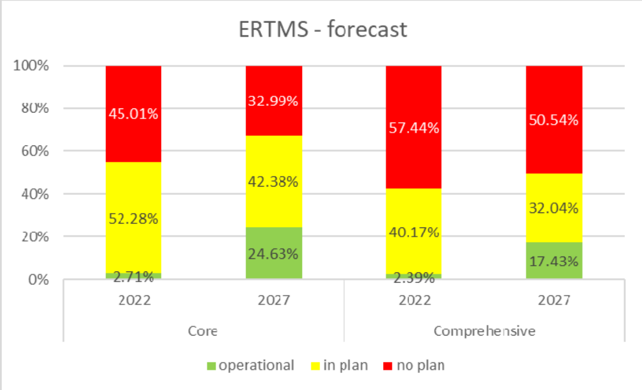

Fig. 5. ERTMS - forecast 2027

5. CONCLUSION

The reason why the greater part of the network is in poor or very poor condition is because of a lack of regular network maintenance and of condition-based maintenance (CBM). This lack of maintenance is due to inappropriate maintenance planning and insufficient funds to cover basic needs in the past. Instead of regular maintenance, therefore, the rail network needs more funds for substantial reconstruction, which leads to even greater traffic disruption later.

A strong tool for overcoming the problem is regular condition-based maintenance based on multi-annual contracts between the Infrastructure Manager and the relevant authority, followed by appropriate on-time funding. This solution is a part of the Transport Community Rail Action Plan and is cheaper and more effective in the long term, since all the negative implications of irregular maintenance are avoided. Negative aspects such as: increased funding for reconstruction, indirect losses because of under-performance, traffic disruptions and safety issues, sometimes multiply the amount needed for regular condition-based maintenance. On top of regular maintenance, application of EU Technical Specifications for Interoperability and TEN-T standards is of key importance.

Beyond the maintenance absence of the reforms and lack of the human resources have a strong negative influence on the successfully implementation of the rail projects. So, this negative trend should be stopped with more investment in education of staff and permanent trainings for the new skills. In terms of that there is idea about establishing Regional center of excellence what will be institution for education and training of railway staff. Since railway transport is one of the greenest transport modes, the future of transport will be on tracks. In the EU Sustainable and Smart Mobility Strategy and the Green Deal Plan, development of a rail transport system is the main focus. The South–East European Parties, therefore, should follow or even set the path for a state-of-the-art, interoperable, sustainable and green transport system by substantial rail system development.

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XX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
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APPLICATION POSSIBILITIES OF RECUPERATED ENERGY OF MODERN RAILWAY HAULING VEHICLES

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Abstract *– The paper deals with the possibility of using recuperated (regenerative) energy from electric railway hauling vehicles. The study considers the importance of efficient energy use in railways and plays a role in the interests of cost-effective rail transport convergence. It examines the current situation and improvement opportunities to achieve efficient energy use. More onboard measurements (seven series) have been executed, during which several parameters were recorded to determine the exact traction (hauling) and recuperated energy. The measurements are related to Railjet trains in Hungary, which are incredibly significant due to the international passenger transport between Germany-Austria-Hungary. The travels of Railjet trains were only considered between Hegyeshalom and Győr railway stations. The value of the recuperated energy can be even 30% of the consumed energy. This significant untapped energy can be used for multiple purposes, e.g., for comfort energy demand (cooling, heating, lighting, etc.) or energy-intensive starts. The paper also examines the optimization of recuperated energy by searching the energy-waste locations and the reasons for the high consumption. The train driver's driving style and habitus were determined as one of the main reasons. Assistance systems are recommended to save energy.*

Keywords – railway, electric locomotive, Railjet, recuperated energy, regenerative energy..

1. INTRODUCTION

In railway transportation, electricity consumption will be critical due to the so-called worldwide energy crisis and the increased price of energy sources [1]. Therefore, it is a logical decision, and it would be a good attitude if the railway companies tried to save money by reducing the overconsumption of electricity. One of the main possibilities is the usage of the so-called recuperated (regenerative) electric energy; however, the current paper tries to investigate the behavior of the train driver, as well as recommends localizing the energy-wasting places on the railway lines. One of the adequate solutions for storing and using the recuperated energy seems to be the onboard battery packs; however, direct charging back to the electric network would be the best solution.

First, the importance of environmental protection should be mentioned regarding the regenerative energy of electric trains. Minaminosono et al. [2] reported that train emission in Japan was measured as 22 g CO_2/km for 1 km of passenger transport. This value is one-sixth of the carbon dioxide emissions of passenger cars and one-fifth of those of airplanes, suggesting that electric railways have environmental benefits. Furthermore, the authors published examples of regenerative energy reaching 47% of running energy on the Yamanote line.

Wang et al. [3] investigated the optimization of the timetable of passenger trains in the Netherlands regarding the regenerative braking energy with MILP (Mixed Integer Linear Programming) models.

In [4], the possibility of charging electric vehicles was analyzed at railway stations at night; three systems solved it: a PV, a 25 kV AC (RTS – railway traction system), additionally a 3 kV DC (RTS supplemented by regenerative braking) system.

The paper [5] compares the energy performance of several rail traction technologies: different "green" technologies based on the regional diesel train "power

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transfer” model. They found that hybridization can achieve energy savings of up to 20% on the non-electrified track studied, compared to 70% for battery traction.

2. POSSIBILITIES OF OPTIMIZING OF ENERGY CONSUMPTION

The investigation aims to increase the energy efficiency of railway transport, analyze the transport system’s complexity and explore the factors causing energy loss. The analysis of the trains considered the routes, as well as examined the energy used. During the test series, on the one hand, the cause of the energy losses is investigated, and on the other hand, possible energy recovery possibilities (locations) are studied. Regarding consumption optimization, four main categories were determined: a) state/condition of the (railway) permanent way and related infrastructure, additionally the railway vehicles; b) energy from regenerative braking; c) external temperature factors; d) role of the human factor. (This paper neglects the condition of the vehicles).

During the examination of the state/condition of the permanent way (a), the aim is to locate the places that waste enormous amounts of energy and find a solution. E.g., where the track geometry is of poor quality, there can be a fault in the track (either superstructure or substructure), overhead line fault, etc. It is also important to note the brake systems of the locomotives.

When using regenerative energy (b), the first goal is the possibility of its usage. In this case, the achievement of higher utilization of recoverable energy. Therefore, search for points where the amount of recoverable energy can be further increased.

For external temperature factors (c), the goal is to analyze the temperature dependence of the consumed energy and determine correction factors.

In the case of examining the human factor (d), it can be observed that consumption and regenerative energy largely depend on the driver’s driving style and habitus. It is important to note that the train driver is not always at fault; wrong “placed” railway signals (redundant or incorrect red signals, unnecessary stopping/braking) cause significant additional energy consumption.

2.1. Analysis and energy optimization process

1. Data collection: a review of electricity consumption data. During the initial step, the larger the database available, the more precisely the problem can be identified.

2. Comparative analysis: based on the balance of energies consumed on the same route (section). It is important to note that the direction of travel must also be taken into account in order to have the exact length-section correspondence (ascents, descents). Another important aspect is the deviations of external factors (e.g., weather); the correction factor for this must be considered.

3. Designation of significant deviations: diving them into smaller sub-sections and locating the place of energy loss. (Such a resolution can be a “division” into sections according to the chainage/sectioning.)

4. Determination of possible error factors: based on options (from a) to d)) defined in Section 2.

5. Possible solution: outlining possible solutions based on the evaluated data.

6. Cost analysis: preparation of choice based on price/value among the solution options.

1. ENERGY EFFICIENCY ANALYSIS

In order to examine the energy efficiency, the actual measurement results were analyzed. A total of seven measurement series between Győr (GY) and Hegyeshalom (HH) railway stations, the related, recorded consumption data are plotted in Fig. 1.

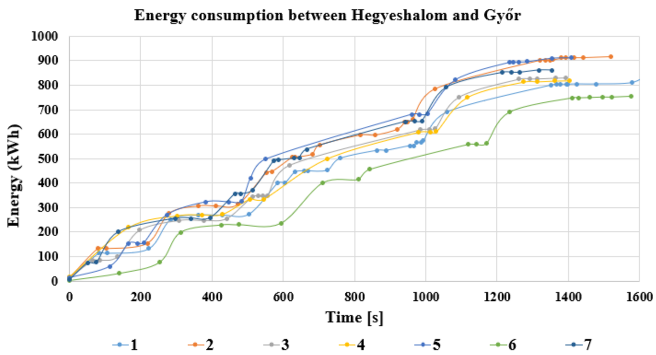

Fig. 1 Energy consumption during the seven series

Fig. 1 shows the distance traveled horizontally; the energy used vertically. The figure shows the seven measurement series performed in different colors. Based on the results, it can be observed that the nature of energy consumption was very similar in all cases, but differences can also be found. Also, there are higher differences between the most efficient and the worst case. The next step of the analysis was the examination of the energy consumption between the different railway stations along the test section. There are two railway stations between Hegyeshalom (HH) and Győr (GY), where most Railjet trains stop: Mosonmagyaróvár (MM) and Öttevény (OT). It is important to note that the trains did not stop here during the first two measurements, so the corresponding results are only estimated.

Remark: the slope (longitudinal inclination) of the Kelenföld (KF) – Hegyeshalom (HH) No. 1 main railway line between HH and GY is between approx. 0…7‰; it is the reason why this factor was neglected during the calculations.

Table 1 summarizes the consumption of individual measurements by stops per railway station.

Tab. 1 Energy efficiency analysis

A) Energy consumption [kWh]

Railway station	Chainage [km]	Dist. [km]	1	2	3	4	5	6	7	MIN	MAX	AVR
Hegyeshalom (HH)	188.0	0	0	0	0	0	0	0	0	0	0	0
Mosonmagyaróvár (MM	176.4	12	270	307	248	273	323	230	256	230	323	272
Öttevény (OT)	154.9	33	690	786	620	610	681	558	652	558	786	657
Győr (GY)	141.2	47	804	914	830	819	912	755	861	755	914	842

B) Energy consumption between railway stations [kWh]

Railway station	Chainage [km]	Dist. [km]	1	2	3	4	5	6	7	MIN	MAX	AVR
Hegyeshalom (HH)	188.0	0	0	0	0	0	0	0	0	0	0	0
Mosonmagyaróvár (MM	176.4	12	270	307	248	273	323	230	256	230	323	272
Öttevény (OT)	154.9	21	420	479	372	337	358	328	396	328	479	384
Győr (GY)	141.2	14	114	128	210	209	231	197	209	114	231	185

C) Consumed energy during measurements [kWh/km]

Railway station	Chainage [km]	Dist. [km]	1	2	3	4	5	6	7	MIN	MAX	AVR
Hegyeshalom (HH)	188.0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mosonmagyaróvár (MM	176.4	12	0.41	0.43	0.36	0.39	0.46	0.33	0.37	0.33	0.46	0.39
Öttevény (OT)	154.9	21	0.36	0.43	0.29	0.26	0.28	0.26	0.31	0.26	0.43	0.31
Győr (GY)	141.2	14	0.12	0.13	0.26	0.25	0.28	0.24	0.25	0.12	0.28	0.22

The meaning of the values in the columns of the tables in all three cases is as follows: the first column shows the location (settlement) of the railway station, the second column is the section number, and the third column is the distance from the starting point. The following seven columns contain the consumption data of the various measurements. The last three columns of the table contain the smallest (MIN), the largest (MAX), and the average (AVR) consumption values. In Table 1 (part A)) the included data contains only the traction and acceleration energy values required to cover the distance between the two stations; furthermore, regenerative energy amounts are not considered in them. There is a significant difference between the largest and the smallest case (159 kWh). Therefore, the location of the largest deviations was determined, and each stop was analyzed separately in part B) (see Table 1). For determinability, the consumption data were divided into smaller distances (railway stations), and the differences between individual sections were observed. For more straightforward interpretation in part C) (Table 1), the energy used is presented together with the distance traveled. In this case, a projected kWh demand of 1 km can already be seen according to the measurements. Based on this, the so-called energy-wasting locations can be easily located. According to the approach, the HH-MM section of measurement series #5 and #6 appear to be cases for further investigation. Therefore, the authors selected the location with the smallest and largest energy consumption. Fig. 2 shows the location with the most significant deviation in these series.

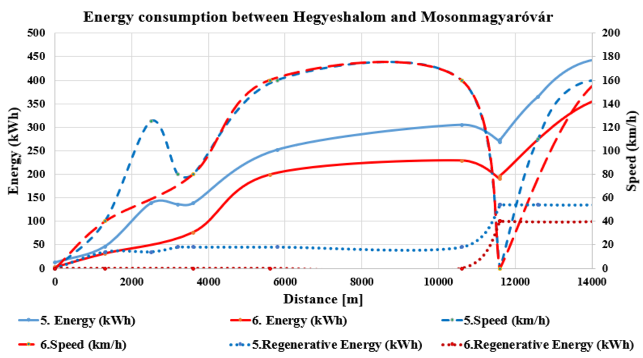

Fig. 2 Energy consumption during series #5 and #6

Fig. 2 shows the section between HH and MM during the #5 (blue) and #6 (red) measurement series (distance: 0-12 km, see Table 1). The solid lines in Fig. 2 show the consumption reduced by regenerative energy, the dashed lines show speed, and the dots show the generated regenerative energy. There is a significant difference in energy consumption around section 2 km, probably due to the different speeds. During series #6, the train accelerated to 160 km/h; significantly more energy was needed than in series #5. Therefore, more regenerative energy can be "produced" due to higher speed, but much more energy is consumed proportionally. Based on this, it can be concluded that individual acceleration and deceleration have a decisive influence on the energy requirement and that the driver has a decisive role in this. However, it is essential to note that the acceleration-deceleration could also have occurred due to traffic reasons, so the consumption does not increase in all cases because of the driver's driving style. (The regenerative energy value reached 30% of the consumed energy, see Fig. 2.)

2. UTILIZATION OF ENERGY DERIVED FROM REGENERATIVE BRAKING

The efficient use of the amount of regenerative energy is of prime importance in increasing efficiency. Fig. 3 demonstrates the connecting measurements.

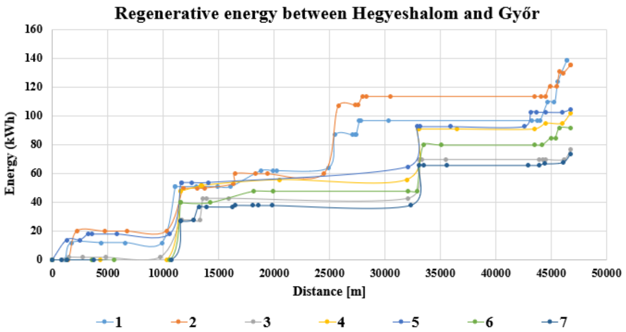

Fig. 3 Regenerative energy generated

It can be seen in Fig. 3 that the braking took place elsewhere during series #2 and #3, the reason for which was that the speed restriction was placed somewhere else at Öttevény. Significant differences can also be discovered in the amount of energy produced during the seven measurement series, possibly due to the driver's driving style and traffic conditions. The production of energy is one important aspect, and the other is its potential uses. Ideally, it can be charged into the network immediately; however, in the cases the authors investigated, this was not possible; so an alternative use would be necessary. One solution could be the energy produced to supply comfort devices (cooling/heating, lighting). Fig. 4 shows the comfort energy demand during the measurement series.

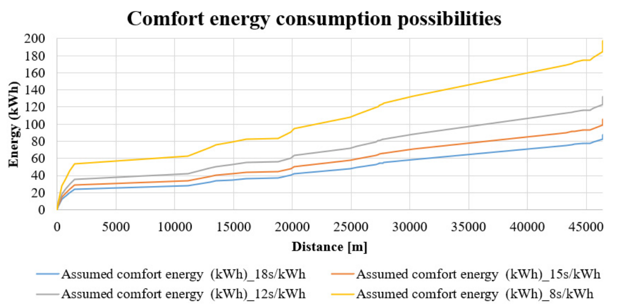

Fig. 4 Comfort energy demand

The consumption data shown in Fig. 4 are estimates and are highly dependent on external factors. The goal is to store the generated energy instead of wasting it and cover part of the comfort needs. Based on the results, a relatively large amount of energy can be stored with the help of a battery supplement, and a significant proportion of the comfort energy demand can be covered (c.f., values in Figs. 3 and 4).

3. CONCLUSION

The paper deals with the possibility of using regenerative energy; the study is based on seven measurement series executed by Railjet trains in Hungary. The considered section was the line segment of Hegyeshalom and Győr railway stations. During the measurements, several parameters were recorded to determine the exact traction and regenerative energy. The value of the recuperated energy can be even 30% of the total consumed energy. This significant untapped energy can be used for multiple purposes: comfort energy demand (cooling, heating) or energy-intensive starts. The paper also examined the optimization of recuperated energy by searching the energy-waste locations and the reasons for the high consumption. Overall, two major influencing factors were defined: the speed restrictions (quantities and locations) and the locomotive driver's driving style. The solutions can include keeping the track/vehicle/other infrastructure in good condition vs. introducing speed restrictions; and/or using assistance systems. These systems help with optimal acceleration and deceleration.

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AUTONOMOUS ROBOT FOR TRAIN UNDERCARRIAGE VISUAL INSPECTION

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***Abstract** – Vehicle inspection and maintenance are seen as one of the huge potentials for robots' application. Inspection robots, especially in railway sector have been used to gradually replace humans. In that way, more accurate, reliable, cost-effective inspection has been provided and what is the most important safety and reliability of the vehicles has been guaranteed. Autonomous undercarriage visual inspection system (ATUVIS) has been developed to bring numerous benefits such as: reducing costs, increase human safety and protect the environment. An autonomous robot represents unique solution to inspect vehicle directly on the track, save time, decrease human labor and energy consumption in comparison with traditional visual inspection (VI). Having in mind that safety legislation requires from all passenger and freight trains to be regularly inspected, where no national exceptions to the inspection rule have been identified, presented solution are seen as applicable and more than needed to perform VI instead of humans. This product was designed to be able to find part of undercarriage that is important to inspect, detect defects on that part and to create inspection record, storing reports in the cloud etc. In this paper the main aspects of the innovative solution for VI robotic application were presented.*

Keywords – Maintenance, visual inspection, autonomous robot, train undercarriage, artificial intelligence.

1. INTRODUCTION

Railways in Europe are considered as the safest in the world, having one passenger fatality on each 25 billion km on average [1]. With 1,721 significant accidents in 2018 resulting in 885 fatalities and 760 serious injuries, the total costs of railway accidents were estimated at about 3.8 billion EUR [1], highlighting the need for further development to mitigate future failures and to solve existing challenges regarding predictive maintenance. Safety legislation requires all passenger and freight trains to be regularly inspected. No national exceptions to the inspection rule have been identified, meaning that all owners of train engines must comply with this requirement. The challenge is to develop a safety inspection system that can perform while the train is in operation.

On the other hand, report results of the Allied Market Research shown that the inspection robots market size was valued at $940.0 million in 2020, and has been projected to reach $13,942.5 million by

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2030, growing at a CAGR of 30.9% from 2021 to 2030 [2]. It should be emphasized the emerging need to use inspection robots in railway sector, to efficiently manage daily operation’s needs. Smart Railway represents integration of the Internet of Things (IoT), cloud computing, artificial intelligence (AI), machine learning (ML) in order to make rail operations more efficient, reliable and secure. The global smart railway market was valued at $18,304.8 million in 2019, and is projected to reach $38,469.7 million by 2027, registering a CAGR of 12.8% [3].

According to the Vithanage *et al*. [4] the growing interest and demand for autonomous systems application in railway maintenance sector is due to the increased competition, rapid expansion and increasing expenses. Inspection robots have become increasingly popular for various railway structures. The benefits of inspection robots are seen in: saving human inspectors from dangerous environments and tedious inspection work, providing more standardized and objective railway inspection than human inspectors, reducing inspection cost, and improving digitalization of railway assets management [5].

Undercarriage visual inspection (VI) represents the industry norm to check the correctness of rolling stock, braking systems and other devices and assemblies. VI is usually performed every week, for stock that has not been used for more than five days before reuse and for suspected defects. Without VI locomotives cannot operate. The installation of mobile assemblies is costly, time consuming and they become not compliant with recent structures.

VI currently requires the train to be taken out of service and transferred to a static inspection pit. The associated ‘down-time’ and VI costs, translate into a reduction of revenues for train operators and a need for higher redundancy in the system to meet passenger and freight demands. Liberalization of the rail operator market has introduced many smaller specialized players who have a limited number of locomotives and who cannot invest in their own inspection pit. Inspection services must be outsourced to certified providers and track time bought to transfer the engine.

The challenge was to develop a safety inspection system that can perform while the train is in operation. This challenge was initially identified during collaborative work on locomotive maintenance between the Serbian cargo operator Despotija and the Faculty of Mechanical Engineering Niš. Further investigations showed that other national and regional operators, (Serbia cargo and passenger operators and Bulgarian BDZ Cargo), are also facing this challenge. Wider research shows that this is an area of active R&D with companies like German DB beginning to form strategic alliances with R&D providers who are developing on-track solutions.

The existing market are still covered with large rail operators with their own inspection pits where people work in and do VI in a traditional way. The largest market share belongs to the traditional way of VI (> 95%). Market saturation based on traditional way of VI has to be considered as good investment opportunity rather than disadvantage. Analysis of market saturation has been shown that there are several competitors providing different technologies to enter the market and shift to machine vision inspection. These competitors are new with their VI rail solutions, some of them have just entered market and rest of them are still in development phase. It can be divided on three categories:

- fixed on track systems by Gatekeeper, UK [6], Westminster, UK [7].
- on track guided mobile robots by Beijing Ctrowell, China, Perceptual Robotics Laboratory, Italy (in development) [8].
- pit robots by Railway BBG, China [9] and Gestalt Robotics, Germany [10].

There is very limited number of robotic/IoT solutions for train undercarriage VI and this sector represent very interesting opportunity for research and implementation of IoT technologies. In this paper is presented an innovative robotic solution for train undercarriage visual inspection with AI application.

2. ATUVIS – AUTONOMOUS ROBOT FOR TRAIN UNDERCARRIAGE VISUAL INSPECTION

ATUVIS is currently TRL6 patent pending solution developed within consortium of CAM-Engineering d.o.o. Novi Sad, Faculty of Mechanical Engineering, University of Niš and Institute Mihajlo Pupin, University of Belgrade.

ATUVIS represents an innovative solution in order to boost further digitalization of the processes in the railway industry. ATUVIS as autonomous robot is replacing the traditional way of VI that relates to direct VI by humans. The largest market share belongs to the traditional way of VI (more than 95%). On the other hand, there are strong commitments and projections in speed up digitalization aiming at the smart railway industry to be fulfilled by the railway sector.

The project proposes the solution of marketable and competitive automated system for train undercarriage visual inspection which can be performed on the track. The main goal of the project is to create the robot that can finished VI just by putting the robot between the tracks and activate the VI on a button. This product is designed to be easy to use, easy to mount, operative on open track, able to find part of undercarriage that is important for inspection, detect defects on that part and to create inspection record, storing reports in the cloud etc.

(Fig.1). These all gives high added value to the clients since it opens the possibility of starting predictive maintenance with locomotives, monitoring of the possible defects and in the case of soon failure to inform operator that specific part of locomotive needs to be repair. ATUVIS decrease maintenance costs, improve rail transport safety and personal safety, reduce operation costs, increase capacity and efficiency and decrease power consumption and railroad exploitation.

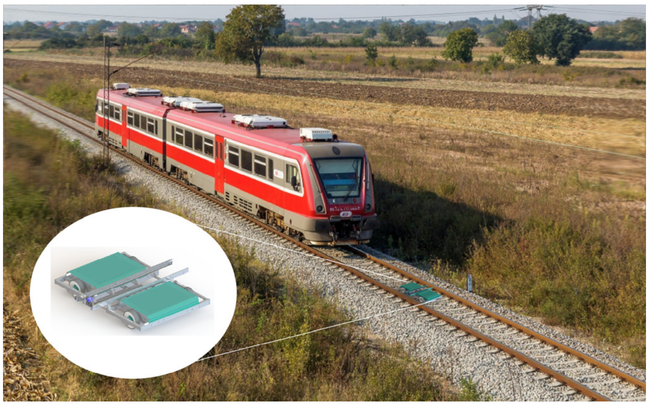

Fig.1. ATUVIS positioned on the track

Besides ATUVIS advantages over human VI, there are several key advantages over other ICT solutions:

- possibility to move along the track without guiding rail or mechanism provides that ATUVIS is faster
- cognitive awareness of the robot and camera position results that ATUVIS is more reliable and more accurate in defect recognition
- ability to operate everywhere on rail provides ATUVIS to be more flexible and less demanded.

The innovative system encompasses two components: hardware (autonomous robot) and software (based on Artificial Intelligence) for visual inspection and defects identification. Separate products are also possible (hardware and software), as they can function independently.

Development of software for ATUVIS that use cognitive positioning/machine recognition and artificial intelligence and will be able to carry out autonomous inspection and it will be software upgrade hardware. In this case visual inspector is not necessary since hardware with software ATUVIS will be able to carry out an inspection by moving ATUVIS robot under the locomotive from beginning to the end and to stop on every for inspection important part using cognitive positioning/machine recognition and to inspect it by using artificial intelligence for comparation of images in database and on site made images.

ATUVIS robot can move and maintain direction in the limited space between track on rough terrain due to sleepers and broken stone tamping. It is completely wireless controlled robot equipped with two motors connected to traction wheels which allows the robot to slightly change direction and to follow pathway between tracks. The robot caries Camera GoPro Hero 8 that can be moved in direction perpendicular to the track. Such technical solution enables positioning of camera to any position below the train (Fig.2).

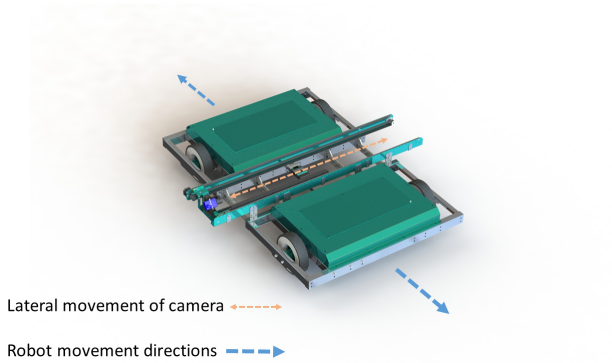

Fig.2. Camera position and direction of movement according to the track

3. DESIGN OF THE ATUVIS ROBOT

The robotic system for visual inspection of the undercarriage of a railway vehicle includes several subsystems.

Concepts of the most important subsystems are defined as:

1. Robot platform;
2. Device for visual inspection;
3. Device for lateral positioning of the device for visual inspection;
4. Power supply;
5. Lighting subsystem;
6. Control system.

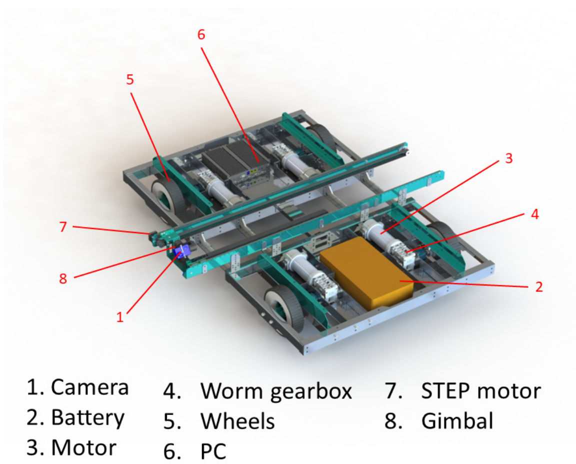

Fig.3. Parts of the robot's subsystem

The robot platform is manually remote controlled, although being configured to operate autonomously.

The control means are provided in the robot platform. The control means are configured with an algorithm which is defined as artificial intelligence. It also comprises distance sensors which enable the determination of the angle α and wheels (position 5 – Fig.3). The robot platform is encapsulated with a larger and a smaller shield.

The robot platform is covered and connected to a thin shield, which consists of a larger and a smaller shield (Fig.2). The function of the larger and smaller shield is to increase rigidity and to protect the interior of the robot platform. On the larger and the smaller shield, distance sensors are mounted, which send data about the distance of the robot platform from the rails.

The function of the visual inspection device is to collect images that are transferred to software that performs the position recognition and the operation condition. With the 3G/4G/5G communication device, images are sent to a remote location for storage. Also, with the help of 3G/4G/5G communication device, it is possible to access the visual inspection device from a remote location and to monitor in real-time the condition of the railway vehicle. A distance sensor of the visual inspection device is mounted on the visual inspection device, which sends information on the distance of the robot from the environment.

Camera (pos.1 – Fig.3) collect images that are transferred to software that performs the position recognition and the operation condition. The wireless communication means communicates through 3G / 4G / 5G communication standards or other local area or world area wireless communication protocols and sends to a remote location for storage.

The optical means comprises a digital camera. The digital camera is able to pan and tilt, and optionally to zoom. The change of pan and tilt with endless positioning capabilities and variable lighting allows human-like performance by inspection of all components from different angles without blocked views/shadows. Zoom allows magnifying a region of interest thus achieving better than human and competitive solutions performance in visual inspection.

Also, the wireless communication means enable access to the optical means from a remote location and to monitor in real-time the condition of the vehicle.

Distance sensors are mounted on the robot platform, sending information on the distance of the device from the environment, such as the distance from rails.

The device for lateral positioning of the visual inspection device consists of a guide system, a carrier plate connected to the guide system, an encoder through which the position of the carrier plate and a drive device are determined. Guides are connected to a larger base plate and a smaller base plate. The visual inspection device is connected with detachable connection to the support plate. The drive device moves the support plate, and thus the visual inspection device, via a guide system. The device for lateral positioning of the visual inspection device aims to translational move the visual inspection device from the left end point to the right end point, i.e. from one side to the other of the vehicle being inspected, and vice versa.

The lighting subsystem consists of several light sources arranged on the shield of the robotic platform and are connected with detachable connection to the platform. The light sources are connected via electronics to the electronics through which the light sources are powered. The light intensity is adjusted via controller.

The control system includes hardware and software part. The hardware part comprises a computer, which has the function of a basic controller and several controllers which control the lower levels of the system that require control, such as movement device, i.e. control the wheels and lateral positioning device for visual inspection device. Software part consists of software implementation and implementation of intelligent control algorithms with user interface as well as software system for positioning and checking the operating conditions.

The control system of the robotic platform includes two basic subsystems for lower-level control, namely:

- A movement device through which the movement of the point is controlled;
- Device for lateral positioning of visual inspection devices.

4. DESIGN OF COGNITIVE POSITIONING SYSTEM

In order to form the basic elements of cognitive awareness of the robot, the basis of labelling has been introduced. The most important camera position of ATUVIS robot has been provided. This would be the basis to form the dataset of images of undercarriage components.

4.1. Labelling

Data labelling for computer vision drawing represents a digital outline around objects in a picture so that the computer can distinguish the different parts of the picture for classification to provide a basis for data processing and machine learning. There are numbers of software for labelling of images. One software platform is Hasty that can be used for the ATUVIS purpose.

For the proper definition of images with annotation is first of all necessary to define classes. Classes need to be defined according to the details on the image that need to be recognized with machine vision. For this test are defined following three classes: wheel, shaft and gearbox (Fig.4).

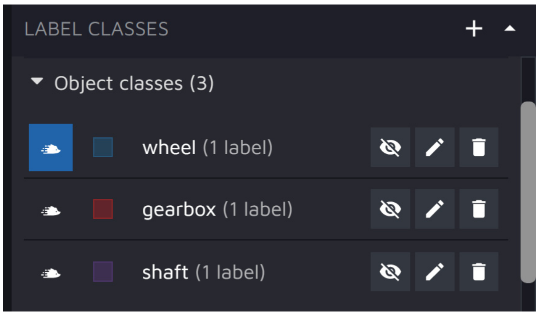

Fig.4. Label classes

After the label classes are defined, then the annotation should follow. For the simple annotation it is needed to draw bounding box around the objects on the image. Every bounding box need to be defined with one class. In the Fig.5 are defined three bounding boxes and for each needed to be assign with one class. Hasty is giving opportunity to have manual review of classes per image (Fig.6).

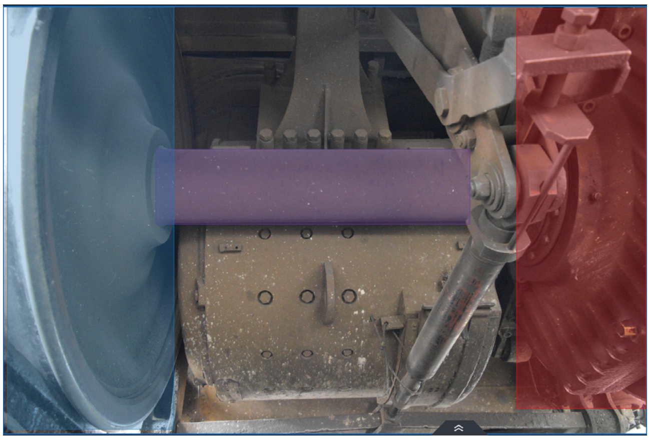

Fig.5. Labelled image with three bounding boxes

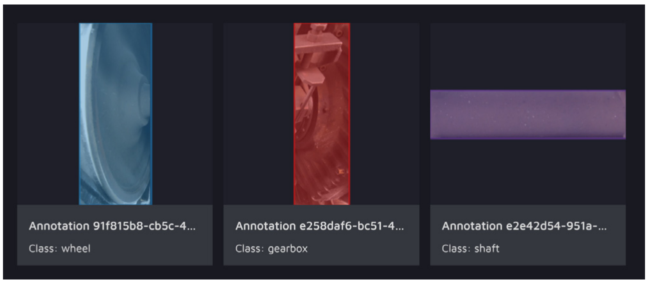

Fig.6. Manual review of image with labels according to classes

4.2. Cognitive positioning based on machine vision

In order to form the basic elements of cognitive awareness of the robot, the cognitive positioning based on machine vision has been introduced. The possibilities of using distance determination in the ATUVIS project has been provided. This would be the basis to form the dataset of images of undercarriage components.

Cognitive positioning applied in the ATUVIS has the aim to determine the position of the robot and the camera undercarriage of the locomotive. Only the positioning of the robot and the camera under the train can be determined in several ways, but since the visual inspection is based by using artificial intelligence and machine vision, this means that in the process, images are created from which the operational correctness of the undercarriage elements is determined. Given that this is the basic function of the ATUVIS robot and images already exist, the same images or the same and additional images could be used for cognitive positioning.

Cognitive positioning based on machine vision could be primary, i.e. in that case other variants of position determination are the ones that confirm or correct this, while other possible variants would be that position is determined based on machine vision, i.e. another way of positioning is taken as basic, and to confirm the position or its correction through machine vision. Each type of distance determination carries a certain error, so it would be possible to determine by trial what is better to use as the primary way of determining the position.

Using machine vision based on digital images, it is possible to determine the distance, which has been confirmed in works dealing with this topic. According to [11] the distance was measured between the base vehicle on which the camera is and the target vehicle. The vehicles were less than 30 meters apart, and through machine vision it was experimentally determined that the error was less than 5%.

If the error is too high for the needs of the ATUVIS application by determining one distance, then multiple recognition of the position could be performed by recognizing two or more elements from one or more images and thus increasing the reliability in determining the position. In the specific case, it could be to determine two distances based on the photo. It is also possible, after positioning the robot and taking a photo, to turn the camera towards another element and take a photo and determine the distance.

5. ATUVIS SYSTEM TESTING

The ATUVIS hardware TRL6 Prototype was designed, constructed, and prepared for testing in the real environment. The testing procedure was planned to prove that the ATUVIS TRL6 Prototype is capable to: move over rough terrain, take any desirable undercarriage position in length of 20 m, position the camera in lateral direction between the rails larger than 1200 mm, adjust the intensity of lighting and transmit remotely video stream.

Before testing in the real environment, ATUVIS prototype was successfully tested in Laboratory environment at the Faculty of Mechanical Engineering Niš (Fig.7).

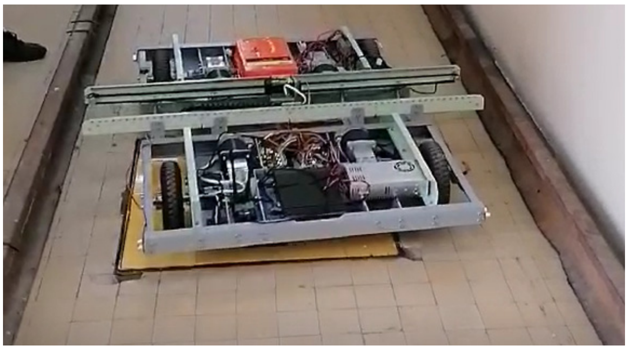

Fig.7. ATUVIS prototype testing in Laboratory at the Faculty of Mechanical Engineering Niš

The testing was performed on the new railway track, with concrete rail sleepers (Fig.8) and on the old railway track, with wooden rail sleepers (Fig.9) and with standing locomotive on the track (Fig.10).

Fig.8. ATUVIS prototype on the track with concrete sleepers on the track

Fig.9. ATUVIS prototype on the track with wooden sleepers on the track

During testing it was observed that ATUVIS prototype: is capable to move in the space between the rails of 1,435 mm without collisions with the elements of the track infrastructure; is capable to move over the rough terrain and overcome differences in height between the sleepers and rock infill, smaller than 5 cm; is capable to take any undercarriage position without collisions of the robot elements with the train undercarriage; is capable to position the camera in lateral direction without collisions of the camera with the train undercarriage. It can cover 1280 mm; is capable to acquire video stream video footage of the underframe regardless of the environmental lighting conditions, it is possible to change continuously between 0 -1200 LM; is capable to transmit remotely video stream to a computer via the internet or WiFi connection.

Fig.10. ATUVIS prototype on the track with standing locomotive on the track

The following conclusions have been made:

- the camera should be lowered by another 1.5 cm min. The top of the camera should be levelled with the robot cover.
- the toothed belt bearing should be rotated by 90 degrees. The rail carrier can be shortened almost to the end of the rail, which reduces the risk of the rail hitting the wheel from the side.
- the ultrasonic positioning works well, if the rail supports are shortened there should be no problem.

Since all the tests were finished successfully, the ATUVIS TRL6 prototype can be considered as successful as well.

5.1. Labelling of images of undercarriage components for dataset creation for AI defect recognition software

In order to start to form AI defect recognition software, the dataset of images of undercarriage was collected. Based on a detailed analysis of defects occurring, it was noticed that the most dangerous defects occur in the braking system. For the AI defect recognition software, exactly the cases of defects detection in the braking system were considered.

In order to use AI for defects detection in the braking system two critical cases were considered, that are presented below.

First case was the Brake system defects that can be seen as: There is or there is not a brake shoe and Centricity of the braking shoe should be in relation to the wheel – i.e. the centre of rotation of the wheel must be centric with the curvature of the braking shoe.

First step to identify whether there is or there is not a brake shoe was analysed. As it can be seen clearly in the Fig.11 there is a breaking shoe, marked with red.

Fig.11. Breaking shoe is clearly visible

Second step was to analyse the centricity of the braking shoe that should be in relation to the wheel – i.e. the centre of rotation of the wheel must be centric with the curvature of the braking shoe. As it can be seen in the Fig.12 the centricity of the braking shoe is not in compliance with the wheel. If the second condition is not met, then there is some defect. It is not known which defect it is; it is important that we detected the defect and it should be investigated later.

Fig.12. Braking shoe and the wheel centricity

Fig.13. Essential connecting screws are clearly visible

Second case was to inspect the essential screws and essential screw connections. This case involves the inspection of essential screws and essential screw connections, and it will be used for AI to check whether they exist or not. As it can be seen in Fig.13 there are essential connecting screws, and they are marked.

6. CONCLUSION

This paper presents a solution for smart train undercarriage inspection combining an autonomous robot with AI to replace traditional visual inspection.

ATUVIS has been seen as cost benefit solution for clients, increasing human safety and has positive impact on the environment; as it can reduce operating costs, reduce maintenance costs, increase of capacity performed freight, increase of efficiency of each locomotive, improve personal safety, improve of rail transport safety, decrease power consumption, and railroad exploitation.

ATUVIS platform technologies has great potential moving to adjacent sectors where it can be used for VI of other vehicle types. This technology can be implicated in all applications where cognitive positioning is needed.

The proposed prototype has been already recognized as scientific technical solution with practical application that would benefit customers but at the same time a reliable sustainable product for preserving the environment.

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MONOGRAPH – TWENTY RAILCON CONFERENCES 1984-2022

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Abstract *– The first conference on railways in Niš was held in 1984 and up to now days it has been held biyearly – time span of 38 years where 20 conferences happened. The initial conferences aimed at the railway vehicles only: their design, structure and application and the participants were railway and industrial experts and university scientists. This railway conference eventually got the name RAILCON/ŽELKON. New scientific knowledge, globalization of the world market, and rapid technological development have caused changes in all areas of life. Accordingly, the railway conference was changing and adapting to current processes, as well. The topics of the conference became infrastructure, maintenance, quality, strategy, politics, future of the railways etc, while audience and participants of the conferences remained the same. This year's XX International Scientific-Expert Conference on Railways RAILCON '22 is a jubilee, milestone or a check point where has to be summarized what has happened in the previous period in fields of railway, university, industry and society thru the scope of the Želkon/Railcon Conference.*

Keywords – ŽELKON, RAILCON, Railway Conferences, Scientific-Expert Meeting, History.

1. INTRODUCTION

It has been 38 years since the first meeting on railway engineering held in Niš, and during that period, the railway has seen significant changes. New scientific knowledge, globalization of the world market, and rapid technological development have caused changes in all areas of life, including the railway industry, transport, and education. The initial railway conference - RAILCON has changed and adapt to current events/processes/trends, as well. However, RAILCON has preserved some tradition within.

The railway conference began as a Yugoslav gathering of experts and scientists dealing only with the railway vehicles. Over the past 38 years, it has transformed into a gathering of experts and scientist dealing with railways in all its aspects: traffic, politics, vehicles, infrastructure, maintenance, education etc.

The Monograph about twenty railway conferences which were held last 38 years is edited as part of the RAILCON conference 2022. The aim of this publication is to summarize and describe all railway meetings held in Niš during the previous conferences [1-9]. The authors of this monograph, and the rest of the past and present RAILCON organizers, did their best to preserve the memories of the events in which experts of various profiles showed exceptional interest and devotion to the railways.

2. THE FIRST MEETING: „CONFERENCE ON RAILWAY ENGINEERING"

The first meeting of railway experts and scientists was held on 2 and 3 of October 1984, in Niš with the title „Conference on Railway Engineering". It was organized by the Faculty of Mechanical Engineering in Niš and Mechanical Industry Niš, on the occasion of one hundred years of the railways in Serbia and hundred years of work of the Mechanical Industry Niš (MIN). The initiator of this meeting and the President of the Organizing Committee was professor Stojan Stojčić.

At the first Conference, 29 papers were presented with the participation of over 150 eminent experts of Yugoslav railways, from the domestic industry of rail stock, overhaulers, researchers from mechanical and electrical engineering faculties, and scientific research institutions. All papers from the Conference were published in the magazine „Železnice", No. 2, 1985.

One of the initiators and organizers of the first meeting Dragoslav Pajić, dipl. mech. eng, stated: „We considered for a long time what name to give to this meeting (consultations), and finally we decided to call it „Conference on Railway Engineering". We adopted this name, simply because there is a Department for railway engineering at the Faculty of Mechanical Engineering in Niš.

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However, it should be said that „engineering" primarily refers to rolling stock, including all those technical branches that, in addition to mechanical engineering, are involved in the issue of rolling stock: electrical engineering, electronics, technology etc. The term „railway" refers, not directly to the railway as an organization; it refers to manufacturers of railway stock, repairers, scientific research institutes, higher education institutions. It refers to all those branches which exist for the sake of the railways as well for the persons which cannot live without railways.".

Fig. 1 Participants of the first „Conference on Railway Engineering", held on 2 and 3 October, 1984 in Niš

Fig. 2 Details from the Želkon/Railcon Conferences

3. TWENTY CONFERENCES ON RAILWAYS – ŽELKON/RAILCON

After the first meeting (Fig. 1) the „tradition" was established that the next railway conferences will happen in October every second year in Niš. The main organizer was the Faculty of Mechanical Engineering in Niš.

The initial meeting was of a purely national character, with or without the participation of foreign authors. Over the years it has transformed into a railway conference with international participation. Since 2004, the name „railway conference" has been abbreviated to ŽELKON (in Serbian: železnička konferencija) or RAILCON (in English: railway conference). The full internationalization of the conference began in 2012, when the traditional conference on railways in Niš became an international scientific-expert conference on railways – RAILCON.

This year 2022, in accordance with tradition, the twentieth railway conference will be held under the name XX International Scientific-Expert Conference on Railways – RAILCON 22. However, all the traditional participants of the conference on railways, whatever the conference is called, remember the name initial name – ŽELKON.

The period of 38 years has given significant changes to the railways, education, universities, community and the ŽELKON. New scientific knowledge, globalization of the world market, and rapid technological development are the main causes of the changes of the railways. Therefore, they are the initiator of changes on railway conference as well.

The Table 1 shows the basic data of all twenty conferences, starting from the first Conference on Railway Engineering in 1984 until the twentieth International Scientific-Expert Conference on Railways RAILCON 22.

Trying to preserve the history of the railways in Serbia, parts of the ŽELKON conferences in 2004, 2006, 2008, and 2014 were the historical publications on rail transport in Serbia:

- „One hundred and twenty years of railways in Niš", by Nenad Govedarović and Zoran Bundalo, published in 2004;
- „Private narrow-gauge railways in Serbia 1881-2006", by Nenad Govedarović, published in 2006;
- „Tramways/Trams in Serbia 1892-2008", by Nenad Govedarović, published in 2008;
- „Railways of Southeast Serbia 1884-2014", by Nenad Govedarović, published in 2014.

These publications became a significant database of the various information on railways in the region.

4. CHANGES IN THE LAST FOUR DECADES

The origin and development of the Faculty of Mechanical Engineering in Niš are closely related to the Serbian Railways and the Mechanical Industry in Niš. This relation and this long-term cooperation gave birth to the conference on railways ŽELKON.

However, during time, the worlds market, industrial trends, railway technology and the society have changed. These changes induced rational (and irrational) changes of the universities, railways and industrial complex of the region.

4.1. Changes at the university

The system of traditional higher education in Serbia (Yugoslavia) was established during the mid twentieth century. Since the signing of the Bologna Declaration in 1999, many universities in Europe changed significantly. University of Niš, changed as well.

The main goal of the Bologna process was the establishment of a single European area of higher education. The reform of higher education in Serbia was implemented with the aim of ensuring more efficient and flexible studying adapted to European quality standards. The Law on Higher Education of the Republic of Serbia was adopted in 2005, and since then numerous changes have been implemented at the university. Forty years ago, all universities in Serbia were exclusively state-founded and there were only 6 of them. Each technical university, for example, had 3 to 16 study programs or Departments. Today there are 3092 accredited study programs within 246 accredited institutions (both state & private) in higher education in Serbia only.

Due to new scientific discoveries and the extreme rapid development of technique and technology, constant changes in the education system over time are necessary. The goals that were set for engineers, fifty years ago, were aimed at increasing productivity and product quality. But, today those goals are shifting towards requirements, for example, of energy efficiency and ecology, preserving the productivity, improving the quality, with low costs! In addition, we live in a time of rapid overall changes and there is a need to innovate professional knowledge: continuous learning throughout the entire life. The university should provide experts who are able to communicate, to constantly upgrade knowledge, to dedicate their professional skills to current topics, and use modern tools.

The university has experienced significant changes in terms of ownership structure, education models, and financing system in the last 40 years, as well.

Tab. 1 Basic data of all twenty conferences from 1984 to 2022

No.	Date of Event	Meeting Title	President of the Org. Com.	Number of…			
				Papers	Authors	countries	Participants
1.	02-03 /10/1984	SAVETOVANJE O ŽELEZNIČKOM MAŠINSTVU	Prof. dr Stojadin Stojičić	**29**	30	1	150
2.	02-03 /10/1986	JUGOSLOVENSKO SAVETOVANJE O ŽELEZNIČKOM MAŠINSTVU	Prof. dr Stojadin Stojičić	**34**	39	1	
3.	29-30 /09/1988	JUGOSLOVENSKO SAVETOVANJE O ŽELEZNIČKOM MAŠINSTVU	Prof. dr Stojadin Stojičić	**36**	50	2	
4.	04-05 /10/1990	NAUČNO-STRUČNI SKUP O ŽELEZNIČKOM MAŠISNTVU	Prof. dr Stojadin Stojičić	**21**	31	3	
5.	01-02 /10/1992	NAUČNO-STRUČNI SIMPOZIJUM O ŽELEZNIČKOM MAŠISNTVU	Prof. dr Ranđel Bogdanović	**46**	55	1	
6.	05/10/1994	Naučno-stručni simpozijum TEHNIKA ŽELEZNIČKIH VOZILA	Prof. dr Ranđel Bogdanović	**38**	48	1	
7.	01-02 /10/1996	Naučno-stručni simpozijum TEHNIKA ŽELEZNIČKIH VOZILA – ŽELEZNIČKO MAŠINSTVO	Prof. dr Ranđel Bogdanović	**49**	56	2	
8.	29-30 /10/1998	Naučno-stručni simpozijum TEHNIKA ŽELEZNIČKIH VOZILA – ŽELEZNIČKO MAŠINSTVO	Prof. dr Slavko Kepdžija	**47**	82	2	
9.	26-27 /10/2000	Naučno-stručni simpozijum TEHNIKA ŽELEZNIČKIH VOZILA	Doc. dr Radisav Vukadinović	**48**	78	3	
10.	24-25 /10/2002	Konferencija ŽELEZNIČKO MAŠINSTVO	Doc. dr Dušan Stamenković	**50**	82	4	161
11.	21-22 /10/2004	Naučno-stručna konferencija o železnici ŽELKON 04	Prof. dr Miroslav Đurđanović	**67**	117	8	220
12.	19-20 /10/2006	Naučno-stručna konferencija o železnici ŽELKON 06	Prof. dr Dušan Stamenković	**97**	174	8	280
13.	09-10 /10/2008	Naučno-stručna konferencija o železnici ŽELKON 08	Prof. dr Dušan Stamenković	**88**	162	10	190
14.	07-08 /10/2010	Naučno-stručna konferencija o železnici ŽELKON 10	Doc. dr Miloš Milošević	**93**	188	12	220
15.	04-05 /10/2012	XV International Scientific-Expert Conference on Railway RAILCON 12	Doc. dr Miloš Milošević	**88**	178	13	250
16.	09-10 /10/2014	XVI International Scientific-Expert Conference on Railway RAILCON 14	Prof. dr Miloš Milošević	**74**	153	10	220
17.	13-14 /10/2016	XVII International Scientific-Expert Conference on Railway RAILCON 16	Doc. dr Milan Banić	**71**	153	13	180
18.	11-12 /10/2018	XVIII International Scientific-Expert Conference on Railway RAILCON 18	Doc. dr Milan Banić	**74**	161	13	200
19.	15-16 /10/2020	XIX International Scientific-Expert Conference on Railway RAILCON 20	Doc. dr Aleksandar Miltenović	**54**	134	11	110
20.	13-14 /10/2022	XX International Scientific-Expert Conference on Railway RAILCON 22	Prof. dr Aleksandar Miltenović	**54**	126	12	

4.2. Changes in the railways of Serbia

In 1984, three independent railway companies (Belgrade, Novi Sad and Priština) operated on the territory of Serbia. In accordance with the that times law, together with other railway companies from the territory of Yugoslavia, they were united in the so-called The Association of Yugoslav Railways, which coordinated the process of creating timetables, adopted technical regulations and they were in charge of international railway cooperation.

Given the steady decline in the share of railways in the transport market, the process of restructuring Europe's railways was initiated forty years ago. The experiences of EU states and railways have shown that it is possible to put the railway sector on a sound (to the market oriented) basis through the restructuring process. The process of restructuring the railways in Serbia was started after 2000. This process includes the restructuring of the railway company, the restructuring of the state administration in this area and the restructuring of the relationship between the state and the railway company, with the aim of enabling the railway company to operate in a market way.

The Law on Railways was adopted in 2005 and it defined the process of restructuring the railway sector. Then the Directorate for Railways was formed, the Strategy was adopted and the policy for the development of the transport sector in Serbia was adopted.

As part of the restructuring process of the Serbian Railways company, three independent companies were formed in 2015: Infrastructure of the Serbian Railways, which is the manager of the railway infrastructure, Serbia Cargo operator in the transport of goods and „Srbija Voz" operator in passenger transport. Today, a total of 23 railway carriers have licenses to carry out the transport of passengers, goods and transport for their own needs on the infrastructure of the Serbian Railways.

In order to see the business efficiency of the railways today and forty years ago, the table provides a comparative overview of certain data on the railways of Serbia in 1984 and 2020 [10,11].

Tab 2. Comparative data on business years 1984-2020

Comparative data	Business Year	
	1984.	2020.
Volume of passenger transport (put-km/pass-km)	3580×10^6	$159,5 \times 10^6$
volume of freight transport (nt-km/tonne-km)	$9,11 \times 10^9$	$2,61 \times 10^9$
No of employees	46777	10587

It can be clearly seen that in the last forty years there has been a significant decline in transport work on railways in Serbia.

The processes of transformation of the state railway into an independent privatized and traffic-market organized organization and the process of globalization of the railway vehicle industry contributed to this.

Relations in the transport market, the role and position of transport branches have changed significantly during the 20th century. The volume of traffic was constantly increasing, but the development of road and air traffic was significantly faster than the development of railways. Accordingly, their participation in the transportation of goods and passengers also changed. From the beginning, road transport was economically (market-wise) and privately organized and, therefore, very flexible. In contrast, the railway is burdened with numerous regulations/norms and is very difficult to orient technically. There are numerous differences between different railways: gauge, axle load, buffer pressure, profile (gauge), platform height, power supply, train braking system, clutch, etc. The railway industry is oriented towards specific customer requirements and small-scale production.

4.3. Changes in the railway industry of Serbia

In the last four decades, the world railway industry has experienced a process of concentration - several large international industrial systems have become the leading global providers of railway services. Thus, the competition was reduced and the possibility of smaller independent companies successfully performing on the world market was reduced, as well.

Significant capacities of the railway industry in the world were developed in the period from 1950 to 1980, when steam traction was replaced by diesel and electric drives. In that period, the production capacity of the domestic railway industry developed the most. The large demands of railways for vehicles encouraged manufacturers to expand their capacities. However, in the last three decades, the requirements have significantly decreased and this has caused the previously developed capacities to be underutilized. The domestic industry of railway vehicles developed its capacities primarily according to the needs of the Yugoslav railways as well as the large mining and metallurgical combines in the country.

The period from 1980 to 1990 is characterized by stagnation, even a slight decline in the social product. The disintegration of the SFRY, the destruction of war, the sanctions and the bombing of the NATO pact caused great damage and caused a deep disruption in economic flows and the development of railway traffic in Serbia. In this period, the traffic system in Serbia was isolated and the traffic services market narrowed. The decline in the volume of economic activities and the decrease in the standard of the population significantly reduced the demand for transport services and thus transport revenues. The condition of the infrastructure has deteriorated, the age structure and technical obsolescence of the means of transport has become even more pronounced. The large immobilization of transport capacities due to irregular maintenance is especially pronounced. The non-use of capacities led to their accelerated deterioration.

This state of the economy in the country, and especially the situation on the domestic railway market, reflected on the activity and state of the railway industry. Companies that overhauled and manufactured railway vehicles MIN Lokomotiva Niš, Şinvoz Zrenjanin, Bratstvo Subotica, MIN Vagonka Niš, Goša Smederevska palanka and Želvoz Smederevo significantly reduced their production. In addition to these enterprises, many enterprises of mechanical, electrical, metallurgical and other activities produced parts for railway vehicles. These are MINEL Belgrade, EI Niš, Tigar Pirot, PPT Trstenik, „Livnica Požega", „Livnica Kikinda", FIAZ Prokuplje, Krušik Valjevo, Sever Subotica, Novkabel Novi Sad, FASO Vladimirci, MIN Skretnice, MIN Svrljig etc. It is estimated that the industry that was directly or indirectly related to rail vehicles in Serbia had around 25,000 employees at the beginning of the eighties. Unsuccessful privatization of these factories was carried out and many of them went bankrupt. The changes in the rail vehicle industry of Serbia in the last 40 years have, in short, been very unfavorable.

Today, of the previously mentioned factories, only MIN Lokomotiva Niš, Tatravagonka Bratstvo Subotica, Šinvoz Zrenjanin, ŽELVOZ Smederevo and GOŠA Smederevska Palanka operate with significantly smaller production capacities. Meanwhile, two new factories that deal with the production of parts for railway vehicles were built: SIEMENS MOBILITY Kragujevac, and MILANOVIĆ INDUSTRIES GROUP Kragujevac.

These are some of the circumstances in which the ŽELKON conferences were organized/held in the period from 1984 until nowdays.

5. CONCLUSION

The mission of the ŽELKON conference remains to gather scientists and experts from the region, monitor development/innovative projects and current railway regulations, analyze changes in developed railways and indicate the direction of further development of railways in Serbia and the region

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THE EUROPEAN UNION AGENCY FOR RAILWAYS (ERA) ACTIVITIES AND ROLE IN RESEARCH

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Abstract - *The European Commission has acknowledged the challenge of world climate change in the framework of the European Green Deal. In this context, the European Union Agency for Railways (ERA) contributes to the further development and effective functioning of the Single European Railway Area without frontiers, by guaranteeing a high level of railway safety and interoperability, while improving the competitive position of the railway sector. This paper concentrates on an overview of the EU legal framework for the Single European Railway Area focusing on the activities of ERA, and in particular on its role in research.*

Keywords – Railways Framework, Research

1. EU-CONTEXT

Transport should not be seen as an end in itself but as the means of delivering major policy objectives such as decarbonisation, economic growth, and social inclusion. To achieve these objectives, reflection must be done on how railways can play a major role in the future transport system [1].

The European Commission has acknowledged the challenge of world climate change in the framework of the European Green Deal that fixes an ambitious target of 90% transport-related greenhouse gas reduction to be reached by 2050 [2]. Rail is a critical component of both passenger and freight in an integrated multimodal transport system.

In this context, the European Union Agency for Railways (ERA) contributes to the further development and effective functioning of the Single European Railway Area without frontiers, by guaranteeing a high level of railway safety and interoperability, while improving the competitive position of the railway sector.

This paper concentrates on an overview of the EU legal framework for the Single European Railway Area focusing on the activities of ERA, and in particular on its role in research.

2. THE EUROPEAN UNION AGENCY FOR RAILWAYS (ERA)

ERA was founded in 2004 under Regulation (EC) 881/2004. As of 16 June 2019, it became the European Union authority responsible for issuing authorisations for placing railway vehicles on the market, single safety certificates for railway undertakings, and European Rail Traffic Management System (ERTMS) trackside approvals.

ERA's mission is moving Europe towards a sustainable and safe railway system without frontiers based on the following values [3]:

- stakeholder focus;
- ethical values commitment;
- legal compliance;
- staff involvement and development;
- everybody's commitment to quality;
- continuous improvement;
- business continuity;
- information governance;
- a culture of sustainability.

With approximately 200 staff members working in its headquarters in Valenciennes (FR), ERA aims to:

- promote a harmonised approach to railway safety;
- devise the technical and legal framework in order to enable removing technical barriers, and acting as the system authority for ERTMS and telematics applications;
- improve accessibility and use of railway system information;
- act as the European Authority under the 4th

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Railway Package.

ERA as a decentralised body of the European Union, receives its mandate from the European Commission, on the following actions:

- issuing Recommendations to the Commission on Technical Specifications for Interoperability (TSIs), Common Safety Methods (CSMs) and Registers (Infrastructure, Vehicles, National Rules);
- improving the technical development in railway safety focusing on risk management and safety management systems, monitoring safety culture and safety leadership, human and organisational factors and accident investigation methodologies;
- assisting the Member States and the European Commission with dissemination on railway safety and interoperability, training courses, interface between National Safety Authority Supervision, Agency Authorisations, Certifications, and other support activities on request of the stakeholders.

The technical pillar (which was transposed by the Member States by 31 October 2020) added a new task to ERA on:

- monitoring National Safety Authorities, against a compliance scheme or a maturity model and Notified Bodies (audits and inspections).

3. THE TARGET RAILWAY SYSTEM AND ERA'S ROLE IN RESEARCH

Why is a target railway system needed?

To have a more efficient and effective functioning of the railway system, including its evolution, a comprehensive inventory of the basic features of the framework is necessary.

A common single vision for the target railway system would serve as a generic guidance for the various initiatives under development to achieve a sustainable transport system.

This framework will allow to:

- Enhance technical and operational harmonisation (TSI);
- Ensure multimodal integration;
- Optimise railway transport system with regard to wider economy, and
- Accommodate and incorporate research & innovation.

What is the concept of target railway system?

The target railway system defines an optimal level of technical and safety harmonisation, making it possible to facilitate, improve and develop railway services within the Union, and with third countries, and to contribute to the completion of the SERA and the progressive achievement of the EU internal market.

How to develop the target railway system?

This would require developing each element of the target railway system in a structured way, involving the main actors, taking account of constraints and opportunities.

The analysis of these elements will allow:

- to identify what needs to be further developed (research and innovation), and
- what needs to be harmonised (regulation and standards).

Several activities are supported by the Agency in the research field:

- collection and coordination of different needs (e.g. closure of open points in TSIs, support to standardisation bodies for definition of new standards), and
- follow-up of the possible solutions identified.

Research and innovation might be necessary to develop identified target system elements. Priorities should be established for those with:

- quick effects on achieving the climate change goals, and
- the less investments needs.

For example, for the case of infrastructure developments, because of their high costs and long time period, innovative solutions may need a specific strategic and financial analysis. Therefore, before deploying and implementing them, a comparison of alternative options should be done to evaluate properly the costs of a change that includes all consequential costs (upstream & downstream).

The target system will probably be reached progressively through several migrations. It is therefore necessary to define securely the various stages of such migrations without unsettling the entire system. Those migrations should take into account the interactions between technical and operational elements of the target system.

Why is ERA involved in research?

ERA is involved in research for the following reasons:

- To influence research so that it supports the policies and framework of a SERA.
- To provide the Commission and the EU-Rail JU with independent specialist railway knowledge.
- To steer research according to ERA strategic statements.

The main ERA research objectives are:

- To ensure that research results support and are consistent with the development of a SERA.

- To facilitate the development of cost-effective approaches to meeting the railway essential requirements.
- To close “open points” in the European Legal Framework.
- To enable ERA recommendations to take full account of recent developments in technology and/or social and societal requirements.
- To be informed of and influence developments in international rail research activities, cooperating with research bodies where appropriate.

4. CONCLUSION

The European Union Agency for Railways contributes to the further development and effective functioning of the SERA.

ERA provides its input on research needs relating to the realisation of the SERA with a vision for the target railway system needed to have a more efficient and effective functioning of the railway system.

ACKNOWLEDGEMENT

ERA’s activities in the development of an effective functioning SERA are done in cooperation with the stakeholders, and the European Commission. Without their help, ERA would not have achieved its current results. ERA is thankful to all of them for the fruitful cooperation.

DISCLAIMER

The views expressed in this paper are those of the authors. They do not necessarily reflect the views of the European Union Agency for Railways or any other EU Institution. This paper is for the purpose of information only. A binding interpretation of EU law is the sole competence of the Court of Justice of the European Union.

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Rolling stock

DEVELOPMENT OF ELASTOMER-BASED COMPONENTS WITH INCREASED LIFETIME FOR REDUCING LCC OF RUNNING GEAR

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Abstract *– The reduction of rolling stock life cycle costs (LCC) is a key objective of stakeholders operating either passenger or freight trains. The running gear is the most complex assembly on a rail vehicle, comprising various sub-assemblies and components that have different functions related to train-track interaction, suspension, stability, comfort, breaking, etc. Therefore, a potential method for reducing LCC of running gear is to increase the lifetime of its most critical components and sub-assemblies, which would allow increasing the time between the scheduled maintenance activities (including the bogie overhaul). This would lead to lower maintenance costs, as well as better availability of the rolling stock. This article presents the activities carried out within the Shift2Rail GEARBODIES project for the development of elastomeric components. Different categories of elastomer-based components were identified and assessed, and two key components have been selected for further development. Dynamic multibody simulations (MBS) have been carried out to determine the loads on components and to analyse the impacts of component parameters on dynamic behaviour of the vehicle. A demonstrator will be implemented, based on the most promising innovative solutions that have been identified; the prototype components will be tested according to standard specifications for validating the results.*

Keywords – Running Gear, Life cycle cost (LCC), Lifetime, Elastomeric materials, Simulations.

1. INTRODUCTION

Technologies for running gear must be durable and reliable enough to operate between overhauls or throughout their designed lifetime. The maintenance process for running gear is, therefore, essential in ensuring a good performance and availability of rolling stock, the optimisation of this process being nowadays a key objective for manufacturers and stakeholders.

In this context, one of the most sensible solutions is the development of innovative running gear component concepts to ensure light, silent, track-friendly, and reliable rolling stock, with lower life cycle costs (LCC). In addition to reducing the overall bogie LCC, the novel components with increased lifetime have also to address key functions of the rolling stock, such as comfort, dynamic behaviour, structural strength, potential for health monitoring, etc.

Work Stream 2 of the GEARBODIES project, which was funded within Innovation Programme 1 (IP1) of Shift2Rail, aims to develop innovative concept designs for railway vehicle running gear components with extended lifetime, and low life cycle costs (LCC), whilst maintaining or increasing current levels of reliability, and maintaining or reducing current levels of noise emissions and track damage, using innovative approaches, materials, tools and methods. The focus is on two key types of components: axle bearings and elastomer-based components. This paper presents the work carried out for the development of two types of elastomer-based components, which will be prototyped and tested in laboratory, according to standard specifications.

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2. ELASTOMER-BASED COMPONENTS FOR RUNNING GEAR

The elastic elements of a suspension, whether primary or secondary, can be made of different materials. The combination of different materials in different designs allows a wide range of possible configurations in suspension design to achieve the same general objectives. The application of rubber and elastomeric materials to create elastic-damping suspension elements in modern railway vehicle is a quite common design solution. Polymer and rubber materials have high absorption properties for the damping of vibration energy, and they can also provide high cushioning characteristics by means of their enhanced properties of elasticity. Elastomers are commonly used materials in running gear components due to their high elasticity, since they can support large deformations under the action of external forces and to recover to original shape when these action forces cease.

Different designs of modern railway vehicles have been analysed in the initial activities of the study to identify different applications of elastomeric materials in the running gear of modern railway vehicles, and a list comprising both entirely elastomeric components and those including elastomer-metal interface(s) was compiled. This list includes running gear components such as springs, airbags, bump stops and bushings, mainly in the primary and secondary suspension of the vehicle (see Figure 1).

The common properties of elastomers, which make them suitable for running gear components, are their low Young's modulus, large elongation-to-break and high Poisson's rate. However, due to the potential variety of compounds of elastomer, interface(s) bonding methods, and geometry used in different components, the actual and optimum properties of individual components vary considerably, which results in the design process for any specific component being extremely complex. The main common drawbacks of elastomeric materials are that their viscoelastic behaviour in response to mechanical inputs is highly non-linear, they experience permanent deformation and softening under cyclic loading, their fatigue and wear behaviour, and the natural aging of rubber. These drawbacks significantly affect the properties of the components over time, which further complicates their design and limits the effective service life of elastomeric components. The service life and degradation mechanisms of elastomeric based components affects the inspection and maintenance regimes of these components, which, along with the initial unit costs, contributes to their overall LCC.

Starting from the preliminary list of elastomeric-based components that have been identified, an initial assessment of the relative priorities for developing different types of components with increased lifetime and reduced LCC was carried out. The assessment was based on the potential benefits of the anticipated developments in terms of LCC, and potential for innovation. LCC-related criteria included the length of the lifetime, the unit cost, maintenance related costs and the criticality in terms of safety of the component;

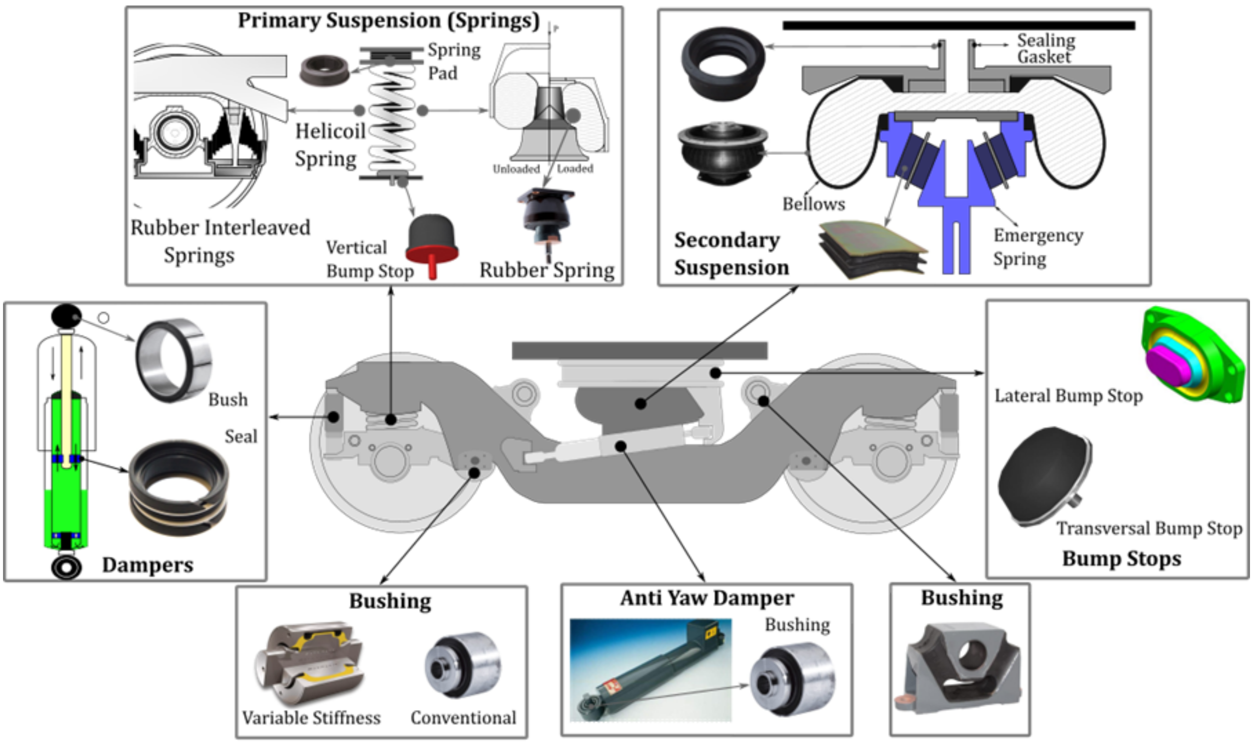

Fig. 1. Illustration of typical elastomer-based components of railway vehicle running gear

criteria related to the potential for innovation considered the potential for the beneficial use of advanced materials, optimised design, novel integrations or functionalities, and barriers to implementation.

Based on the results of the assessment, the candidate components have been shortlisted, as follows: rubber interlevel and conical springs (in primary suspension), air spring and resilient seat/emergency spring (in secondary suspension), coupling articulation, adjustable torque supports, rubber block for secondary suspension, and bushings (in longitudinal or lateral arms and/or links).

3. EVALUATION OF SOLUTIONS FOR ELASTOMER-BASED COMPONENTS WITH INCREASED LIFETIME

Considering the list of candidate elastomer-based components of interest, an analysis was carried out to evaluate and prioritise potential innovations and technical solutions for increasing their lifetime and reducing LCC. A multi-criteria methodology based on the Analytic Hierarchy Process (AHP) [1, 2] has been used to assess the solutions and make a decision on the most promising ones. The AHP considered the most relevant potential improvements and innovations, which have been grouped in three categories of specific objectives (objective functions):

1. Improvement of fatigue resistance;
2. Improvement of elastomer strength (in static conditions);
3. Improvement of resistance to environment and other external factors.

Furthermore, three additional criteria (constraints) have been also taken into account:

1. Effect on component cost/price;
2. Difficulty of implementation of novel solution with respect to foreseen barriers;
3. Compliance with requirements in standards and regulation.

The potential innovations have been evaluated for a shortlist of five selected components:

1. Adjustable torque support;
2. Emergency spring in secondary suspension articulation;
3. Rubber inter-level (chevron-type) spring (in primary suspension);
4. Bushing in longitudinal swing arm;
5. Conical rubber spring (in primary suspension).

After weighting the evaluation results with respect to the effect of proposed solutions on each specific component, these have been ranked as follows:

1. Combined use of carbon nanotubes and other nanomaterials as fillers in the elastomer formulation.
2. Use of carbon nanotubes as filler.
3. Use of other nanomaterials as fillers.
4. Optimisation of elastomer-based component manufacturing process.
5. Measures for improving metal-elastomer interfaces.

The evaluation through the AHP methodology, along with additional comments provided by experts and information available in literature, also allowed an indirect qualitative assessment of the components initially identified and shortlisted, with respect to the expected efficiency of the most relevant innovations for enhancing their LCC. Based on the indirect evaluation, two types of elastomer components have been selected for further analysis and for being prototyped and tested:

- Bush in longitudinal swingarm;
- Conical rubber spring in primary suspension.

4. ANALYSIS OF SELECTED ELASTOMER-BASED COMPONENTS THROUGH MULTIBODY SIMULATION

Further work involved modelling of a relevant high-speed bogie and carrying out multibody simulations (MBS) to determine the loads acting on the selected components; a commercial software package was used for this purpose.

The determined loads would be used as essential inputs into the design process of novel components, and as a benchmark for evaluating and validating the novel components. Three different simulation scenarios, which are compatible with the overall Shift2Rail action plan for Technology Demonstrator (TD) 1.4., have been developed and used, with respect to different track configurations and operating parameters that are representative for typical high-speed lines in Europe. Furthermore, the System Platform Demonstrator SPD1 “high-speed” developed in Shift2Rail was chosen as a reference vehicle concept.

In addition, the MBS results allowed a comparison with specifications in standard EN 13913:2003 [3]. The standard specifies the characteristics to be tested and recommends test cycles for specific ones. Some characteristics and tests in the standard, which consider influences other than mechanical loads, cannot be investigated by performing multibody simulations.

A 70 DoF (degrees of freedom) vehicle model was developed starting from the German train ICE 1 with MD 530 bogies and its parameters. The bogie design has been adapted in accordance with other bogie designs, and the dynamic model parameters have been adjusted accordingly, so that to include the elastomer-based components chosen for investigation and further development (Figure 2).

A stability analysis has been initially carried out to evaluate the critical speed for lateral stability of the system, i.e., the maximum forward speed at which the coach may run with undamped oscillations of any of the wheelsets or undamped yaw oscillations of the carbody. The analysis has validated the model at speeds that are representative for high-speed operation (100 m/s, i.e., 360 km/h and 109 m/s, i.e., 392 km/h).

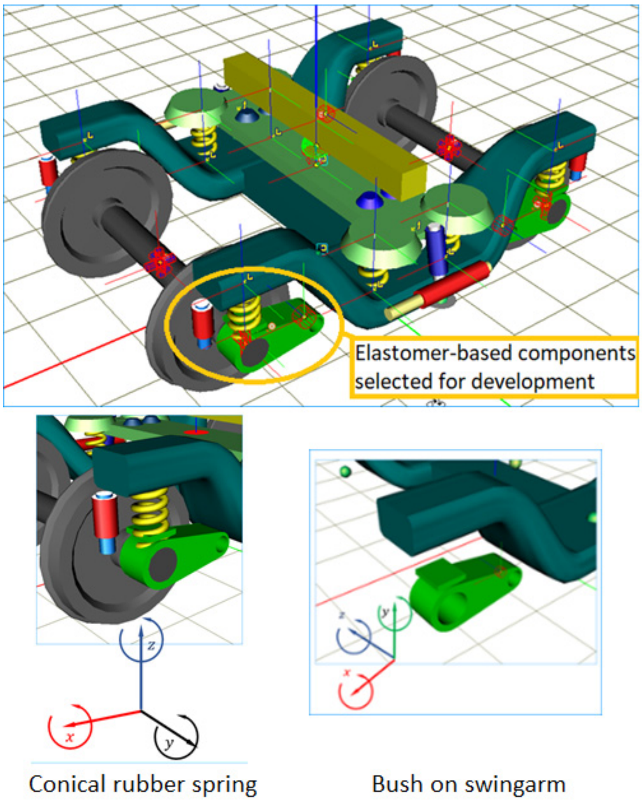

Fig.2. Schematic view of the bogie model

The forces and moments of the two selected elastomeric components have been extracted from simulations in the three different scenarios as both time histories and key values (maxima, minima, and averages), which would be used for the design of the novel components. The stiffness and damping around the characteristic axis of rotation of the bush in the trailing arm is negligible, therefore, the values of the corresponding bushing moments Mz have not been considered. Similarly, the corresponding moments about the z axis of the primary suspension elements are small in the different simulation scenarios. The key values determined through simulations are presented in Tables 1 and 2.

Tab. 1. Maximum, minimum and average values of forces and moments in the conical rubber spring of the front bogie (x: longitudinal, y: vertical, z: lateral axes)

Parameter	Fx [kN]	Fy [kN]	Fz [kN]	Mx [Nm]	My [Nm]	Mz [Nm]
Min of mins	-11.5	-20.8	-57.9	-4404	-3790	-45
Max of aves	5.9	38.1	-51.9	1771	1939	3
Max of maxs	9.7	12.6	-46.9	7181	3237	23

Tab. 2. Maximum, minimum and average values of forces and moments in the trailing arm bushing of the front bogie (x: longitudinal, y: vertical, z: lateral axes)

Parameter	Fx [kN]	Fy [N]	Fz [kN]	Mx [Nm]	My [Nm]	Mz [Nm]
Min of mins	-13.4	-60	-20.3	-6479	-3273	-1
Max of aves	7.5	9	-4.3	-27	631	0
Max of maxs	13.2	80	6.6	6151	3618	1

In addition to the calculated absolute values shown above, the frequencies of the loads play an important role in the test cycle of the elastomeric components; therefore, the calculated loads have been also analysed with respect to occurring frequencies of the forces.

5. CONCLUSIONS AND FURTHER WORK

A wide range of elastomeric-based components used in different running gear designs has been identified and analysed. An in-depth assessment has been carried out to prioritise the potential innovative solutions for increasing the lifetime of elastomeric components, and, also, for selecting the most promising types of components in terms of efficiency of envisaged innovations.

Requirements and specifications have been identified and/or determined for the selected components. Also, dynamic simulations have been carried out to determine the loads on selected components, which would be used as specifications for the novel designs, and to analyse the effect of components' specifications on vehicle dynamics.

Further work will consist of the implementation of selected innovations (based on novel elastomeric materials and improved interfaces) into prototypes of the two types of components, which will be tested according to standard specifications.

ACKNOWLEDGEMENT

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XX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
RAILCON '22

INFLUENCE OF WHEEL TREAD SURFACE ROUGHNESS ON THE NOISE EMITTED BY RAILBOUND FREIGHT VEHICLES

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Abstract *– The increased capacity of freight railway traffic leads to increased noise pollution. The existing regulation TSI NOI defines the maximum noise level allowed to be emitted by railway vehicles. Consequently, the noise tests are mandatory type tests for all new vehicles. Experience from noise tests of different freight wagons have shown that measured noise level depends on many parameters and in most cases is close to the maximum permissible values. Contemporary design of the freight wagons has to be conceived such as to emit as low noise as possible. Accordingly, it is necessary to identify the main influencing sources that affect the noise generation and to find a way to reduce their influence. This paper presents results obtained by measurements of pass-by noise of a freight wagon, with wheels having different wheel tread surface roughness. It appeared that wheel-rail rolling contact as a noise source is very significant and may be critical for assessment of the railbound vehicles.*

Keywords – Railbound vehicles, wheel tread surface roughness, testing, pass-by noise.

1. INTRODUCTION

Railway exterior noise includes a number of different physical sources such as rolling noise, impact noise, traction noise, aerodynamic noise, curving noise, braking noise, horn noise and noise from auxiliary equipment and other components.

Rolling noise is one of the main sources of railway noise. It is generated by the surface roughness (irregularities) in the contact patch between train wheel and rail. This roughness induces vibrations and subsequent sound radiation from wheels, rails and sleepers.

The second member of the contact pair, which has an influence on the noise generation when rolling, is the railway wheel. The surface unevenness might be defined as a roughness deviation (differences between a real wheel radius and the ideal radius). Measurements of wheel roughness have not previously been standardized because the test of the noise generated by different vehicles only requires the control of the test track. This paper presents results obtained by measurements of pass-by noise of a freight wagons, with wheels having different wheel tread surface roughness. Ones corresponding to delivery condition and the other simulating bedding in as the result of running for 1000 km.

1.2 Types of noise test

Noise tests includes measurement sound pressure level inside railbound vehicles and noise emitted into the environment.

Measurements of noise emitted by railbound vehicles into the environment are [2]:

1. stationary noise test (parking noise),
2. constant speed noise test (pass-by noise test),
3. acceleration noise test (starting noise test),
4. braking noise test.

2. CONDITION OF NOISE TESTS

The noise emission contains contributions from the rolling stock, the track and environmental noise.

During noise testing, the following conditions must be met [5]:

1. environmental condition (acoustical

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environment, meteorological conditions and background pressure sound level)

2. track conditions (geometry of line, track superstructure, track quality, acoustic rail roughness [6] and dynamic properties of the track expressed as track decay rates [7])
3. vehicle conditions (loading and operating conditions, wheel tread conditioning and train composition).

2.1 Wagon conditions for constant speed test (pass-by noise test)

According to standard [5], wagon shall be tested in empty condition. The wheel treads shall be as free as possible from irregularities such as flats. The block/tread pair shall be in a run-in condition where block and tread have bedded in sufficiently. Within 24 h before test starting wagon shall be braked starting at 80 km/h until a complete stop with a deceleration which is typical in normal operation (typical main pipe pressure of 4 bars) which ensures that no wheel flats are generated.

Noise from other parts of the train shall not influence the measurements of the vehicle(s) under test. Therefore, for the measurement of a trailed unit, there shall be an acoustically neutral vehicle on one side of at least two units under test, and no vehicle or an acoustically neutral vehicle on the other side (Fig.1).

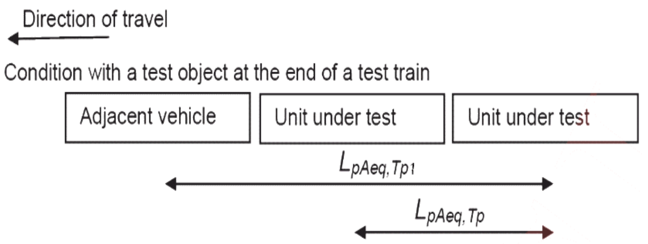

Fig.1. Accessing of the acoustic neutrality of adjacent vehicle

3. TEST RESULT

Laboratory of railway vehicle University of Belgrade was performed pass by noise tests of several types of wagons (Fig.2).

Fig.2. Test wagons pass measurement position

Tab. 1 presents results of measurements for two tank cars and one wagon for containers transportation [8, 10].

Tab. 1. Pass by noise tests results

No	Wagon type	Noise level
1.	Zacns 98 m^3	83 dB
2.	Zacns 88 m^3	83 dB
3.	Sggmrss	83 dB

Results illustrated using examples for pass-by noise measurement of Zacns tank wagon [7].

The basic measured quantities are $L_{pAeq,Tp}$, train speed and pass-by time T_p.

$L_{pAeq,Tp}$ is A-weighted equivalent continuous sound pressure level given by the following formula:

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

where is:

T_p – the measurement time interval in s;
$p_A(t)$ – the A-weighted instantaneous sound pressure at running time t in Pa;
p_o - the reference sound pressure; p_o = 20 μPa

The first test series included four tests at a nominal speed 80 km/h. The second series consisted of five passings at nominal speed 120 km/h. These two series are marked as "right side tests". After that, both tank wagons were turned around vertical axis, and third series with three passes at nominal 80 km/h were performed and thereafter series of four tests at nominal speed 120 km/h. Last two series are marked as "left side tests". At least three measurements at 80 km/h ±5% and three at v_{max} =120 km/h ± 5% should be performed. The results are shown in the table 2.

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

Third column represent the speed measured during the corresponding passing of 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 following equation:

$$L_{pA_{eq},T_p(APL_{ref})} = L_{pA_{eq},T_p(v_{test})} - 10 \cdot \log(APL_{wag}/0{,}0225m^{-1}) - 30 \cdot \log(v_{test}/80\ km/h) \quad [dB] \qquad (2)$$

For the Zacns tank wagon of 98 m^3 is:

$$APL_{wag} = \frac{n}{L_{ob}} = \frac{4}{16{,}4} = 0{,}2439\ m^{-1} \qquad (3)$$

n = 4 is number of axles and

L_{OB} =16,4 m is length over the buffers.

v_{test} is actual speed during the measurement.

After normalization, arithmetic mean value of each series of measurements rounded to the nearest integer decibel is given in table 3.

Table 2 Measurement results

Test	Test side	$L_{pAeq,Tp(vtest)}$ (dB)	v_{test} (km/h)	$L_{pAeq,Tp(APLref)}$ (dB)
80-1	Right side tests	83,9	81,63	83,3
80-2		83,5	78,77	83,4
80-3		83,7	77,31	83,8
80-4		84,1	76,83	84,3
120-1		89,0	120,45	83,3
120-2		89,1	120,71	83,3
120-3		88,6	119,62	83,0
120-4		88,6	120,22	83,0
120-5		88,5	121,87	82,7
80-1	Left side tests	84,1	78,17	84,0
80-2		83,6	78,30	83,5
80-3		82,1	78,31	82,0
120-1		89,6	125,18	83,4
120-2		89,6	122,99	83,6
120-3		88,9	125,76	82,7
121-4		87,7	116,07	82,5
Average rounded to the nearest integer				83

Fig. 3 and 4 show an example of LpA(t) during the pass-by test at 80 and 120 km/h. The red line indicates the passage of each wheel of the train composition.

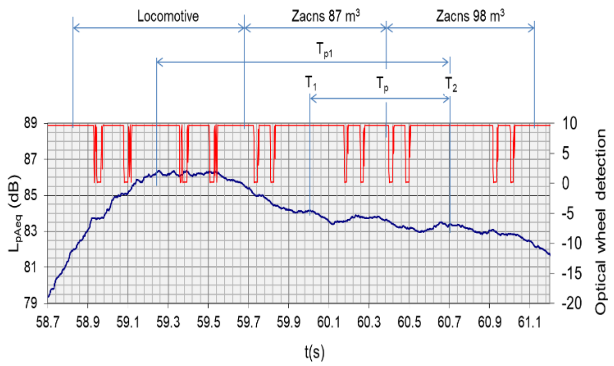

Fig. 3. Example of sound pressure level record at 80 km/h

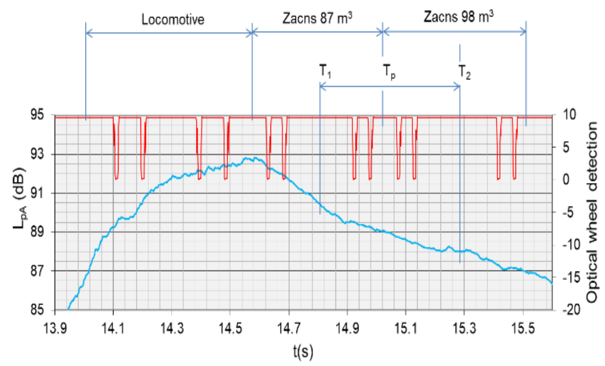

Fig. 4. Example of sound pressure level record at 120 km/h

4. COMPARED TEST RESULTS

In order to experimentally research the effect of wheel tread surface roughness on the noise level, the noise emitted by a rail vehicle was measured. Tank wagon was equipped with new wheels and wheels that have been additionally machining.

The surface finish of new wheels after machining must be 12.5 µm Ra (Roughness Average) or less, as per the meter reading [4].

Fig.5 present test results during the pass-by test at 80 and 120 km/h with new wheel with tread surface roughness 6,5 µm.

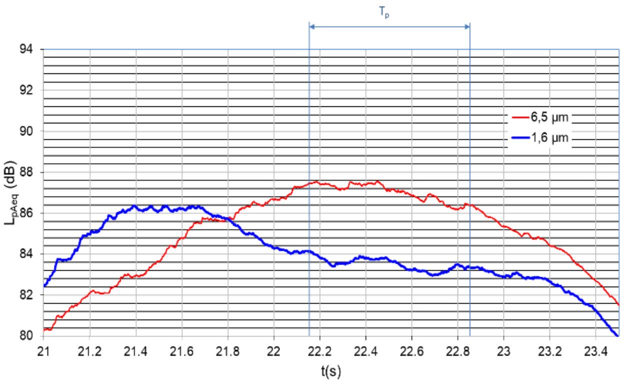

Fig. 5. Sound pressure level record at 80 km/h

After additional machining of the wheel tread surface, a repeated noise test was performed.

Fig. 6 present test results during the pass-by test at 80 and 120 km/h with new wheel with tread surface roughness 1,6 µm.

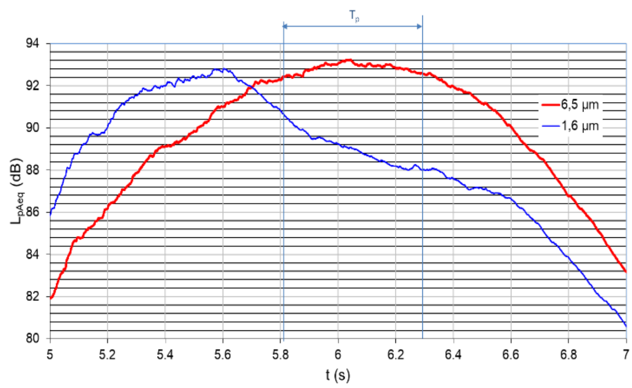

Fig. 6. Sound pressure level record at 120 km/h

Obtained decrease in weighted equivalent continuous sound pressure level in case of measurements with smoother wheel, with Ra=1,6 µm, is 4 dB.

5. CONCLUSION

This paper shows that the new wheels may cause an increased noise level even though they meet the roughness requirement, which is for category 2 of wheels for speeds up to 200 km/h limited to 12,5 µm. Therefore, it is necessary to fully meet the requirement of [5] that the tested vehicle should run at least 1000 km with as much braking as possible. In this way, the tread surface of the wheel will be smoother, and therefore the level of noise emitted by the vehicle will be lower.

ACKNOWLEDGEMENT

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ANALYTICAL CALCULATION OF HOLLOW RAILWAY AXLE IN ACCORDANCE WITH EN 13103

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***Abstract** – The paper presents methodology for analytical strength calculation of hollow axles of railway vehicles. The considered methodology is defined by appropriate international standard EN 13103. The calculation procedure is demonstrated on the concrete example of hollow axle for axle load of 25 tons, and for normal track gauge of 1435 mm. Based on the appropriate authoritative loads, the equivalent stresses in the selected characteristic sections of the axle are determined. They should be compared with the corresponding permissible stresses for the considered sections of hollow axle determined on the basis of the endurance limits in certain sections and the corresponding safety factors. The results of the paper can be very useful for all those who deal with design and optimization of hollow axles of railway vehicles.*

Keywords – Hollow axle calculation, Railway vehicle, Strength calculation, EN 13103.

1. INTRODUCTION

The railway axles belong to the most significant parts in the railway traffic. A numerous experience from the past have shown that failures of these components have caused a large accidents and derailments with huge consequences [1]. In certain cases, failure of only one axle of certain vehicle in the train can cause derailment of the most part or whole train. Because of these facts, requirements for the strength of railway axles are very rigorous and they are precisely defined by international regulations. Given in mind distinctly dynamical character of their loads, railway axles must satisfy prescribed conditions related to the endurance limit. The main aim of design, calculation and production of railway axles is to prevent failure of the axle during the predicted operating life. It is well known from the past that Wöhler had developed his theory of material fatigue studying just failures of the railway axles [2]. To date, the methods of design and calculation of railway axles have significantly improved. Today, a common approach of design of railway axles and wheels is numerical calculation by usage of some of the modern software packages based on the finite element method (FEM) [3-6]. In addition, analytical methods are also important in the design of railway axles, especially in cases when is necessary to perform mathematical optimization of the axle design on the basis of precisely defined aim functions and restraints. One of the main aims of optimization of railway axles is reduction of their mass, which is non-suspended and has a large influence of dynamic behavior of railway vehicles. The approach which is in use for a long time is application of hollow axles. In this sense, the aim of this paper is to present methodology for analytical calculation of strength of hollow railway axles in accordance with the European Standard EN 13103 [7].

2. REPRESENTATIVE LOADS

The representative loads for railway axles calculation are defined by international standard [7]. The principal scheme of these axle loads is shown in Fig. 1, while expressions for determination of loads values for non-guiding axle of normal track gauge are given below.

Forces which act on the axle journals are [7]:

$$P_1 = \left(0.625 + 0.075\frac{h_o}{b}\right) m_1 \cdot g \tag{1}$$

$$P_2 = \left(0.625 - 0.075\frac{h_o}{b}\right) m_1 \cdot g \tag{2}$$

$$H \approx Y_1 - Y_2 \tag{3}$$

Reactive forces in the wheel-rail contact are [7]:

$$Y_1 = 0.3 \cdot m_1 \cdot g \tag{4}$$

$$Y_2 = 0.15 \cdot m_1 \cdot g \tag{5}$$

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$$Q_1 = \frac{1}{2s}\left[P_1\left(b+s\right) - P_2\left(b-s\right) + \left(Y_1 - Y_2\right)\cdot R\right] \quad (6)$$

$$Q_2 = \frac{1}{2s}\left[P_2\left(b+s\right) - P_1\left(b-s\right) - \left(Y_1 - Y_2\right)\cdot R\right] \quad (7)$$

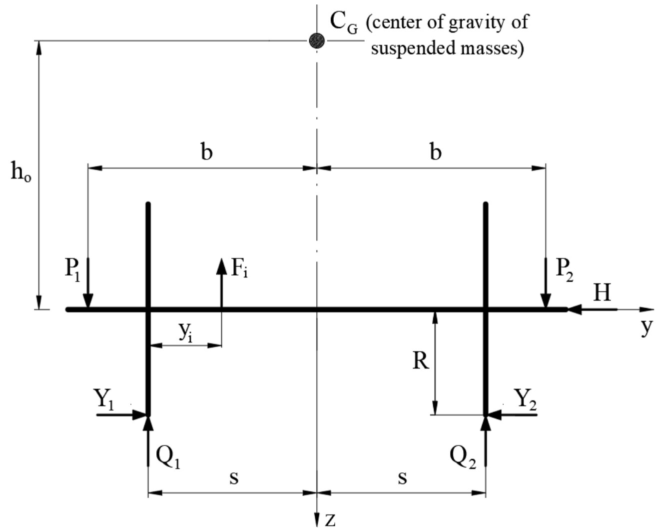

Fig.1. The principal scheme of axle loads

As can be seen, the main parameter for determination of given forces is mass per one axle (m_1), which is defined as difference between axle-load mass (m_{al}) and wheelset mass (m_{ws}):

$$m_1 = m_{al} - m_{ws} \quad (8)$$

The standard also takes into account the influences of braking forces and inertia forces (F_i) on the axle strength.

3. CONSIDERED HOLLOW AXLE

The hollow axle for axle load of 25 t is considered in this paper. This axle is shown in Fig. 2. The characteristic parameters necessary for calculation of given axle are:

m_{ws}=1400 kg – wheelset mass;
h_o=1900 mm – supposed height of center of gravity of suspended mass for loaded wagon;
$2b$=2000 mm – distance between axle-box cases;
$2s$=1500 mm – distance between nominal rolling circles;
D=920 mm – nominal wheel diameter;
F_i=0.

The more details about production of the considered axle are given in [8].

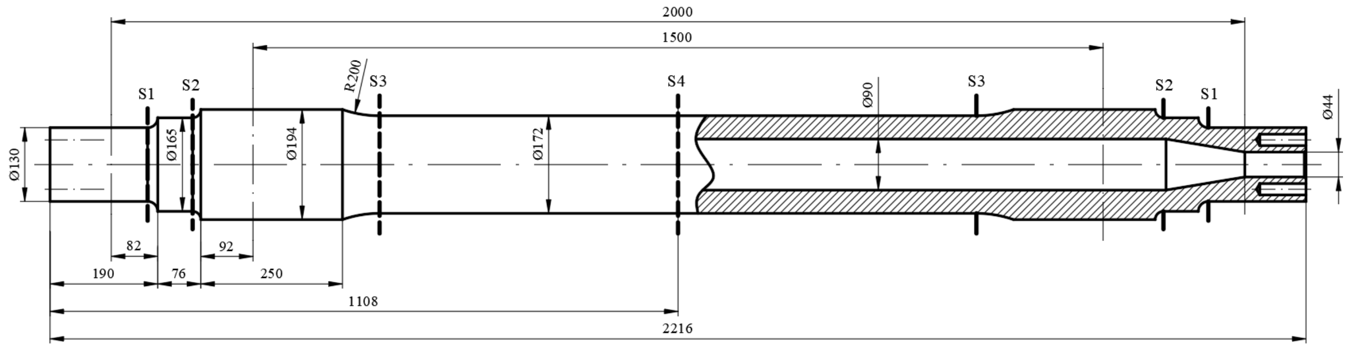

Fig.2. Considered hollow axle [8]

4. CALCULATION RESULTS

The values obtained on the basis of equations 1-8 are shown in the Table 1.

Table 1. The values of representative loads for axle calculation

m_1=23600 kg	Y_1=69.45 kN
P_1=177.69 kN	Y_2=34.73 kN
P_2=111.71 kN	Q_1=199.33 kN
H=34.72 kN	Q_2=90.07 kN

4.1. Axle bending moments

The diagrams of bending moments in yz plane are shown in Fig. 3. The maximum bending moment in yz plane due to braking with two-sided shoe brake made of gray cast iron is determined from the following expression:

$$M_{xbr,\max} = \mu \cdot 0.3 \cdot F_s\left(b-s\right) \quad (9)$$

where:
μ – friction coefficient (for braking with shoe brake made of gray cast iron μ=0.1);
$F_s=B_k \cdot P_w$ – braking force (B_k=0.75 is braking coefficient, P_w=122.625 kN is static load per wheel).

The maximum bending moment in xy plane (diagram in Fig. 4) due to braking is determined from the following expression:

$$M_{zbr,\max} = 0.3 \cdot F_s\left(b-s\right) \quad (10)$$

The torsion moment of axle around y axis (diagram in Fig. 5) due to braking can be determined from the following expression:

$$M_{ytbr} = 0.3 \cdot P_w \cdot R \tag{11}$$

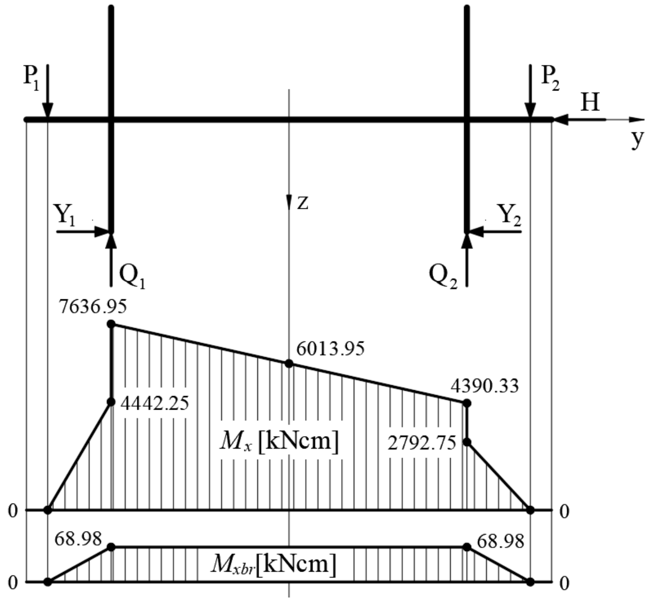

Fig.3. The diagram of bending moments in yz plane

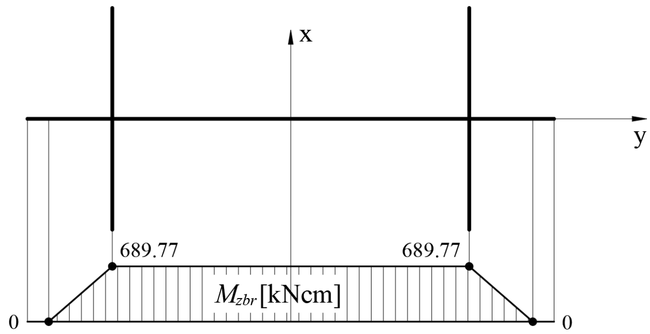

Fig.4. The diagram of bending moments in xy plane

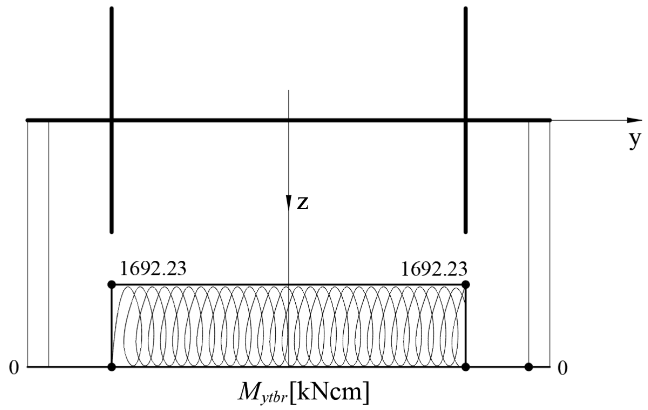

Fig.5. The diagram of bending moments in xy plane

4.2. Axle stresses

Four characteristic sections (S1, S2, S3, S4) for calculation of axle strength are selected, as shown in Fig. 2. In any point of the hollow axle, the equivalent stress is:

$$\sigma_e = \sqrt{\sigma^2 + 4\tau^2} \tag{12}$$

After taking into account the known expressions for normal and tangential stresses as well as the stress concentration factor, the expressions for equivalent stress at the outer and inner surface of the hollow axle $\sigma_{e,out}$ and $\sigma_{e,in}$ is obtained, respectively:

$$\sigma_{e,out} = S_k \cdot \frac{32 \cdot M_e \cdot d_{out}}{\pi\left(d_{out}^4 - d_{in}^4\right)} \tag{13}$$

$$\sigma_{e,in} = S_k \cdot \frac{32 \cdot M_e \cdot d_{in}}{\pi\left(d_{out}^4 - d_{in}^4\right)} \tag{14}$$

where:
S_k – stress concentration factor
$M_e = \sqrt{M_x^2 + M_y^2 + M_z^2}$ – equivalent moment
d_{out} – diameter of section at outer axle surface
d_{in} – diameter of section at inner axle surface

The stress concentration factor S_k is defined with the following expression:

$$S_k = A + 1 \tag{15}$$

where:

$$A = \frac{(4-Y)(Y-1)}{5 \cdot (10X)^{(2.5X+1.5-0.5Y)}} \tag{16}$$

$$X = \frac{r}{D}; \quad Y = \frac{D}{d} \tag{17}$$

The explanation of the parameters in expressions 17 is shown in Fig. 6.

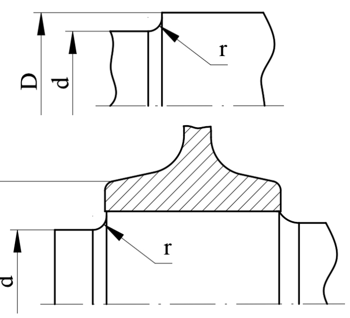

Fig.6. The explanation of parameters in expression 17

On the basis of expressions 13 and 14, the values of equivalent stresses in sections S1, S2, S3 and S4 are calculated. Obtained results of equivalent stresses are shown in the Tables 2–5.

Table 2. The results of equivalent stresses at section S1 of hollow axle

Equivalent moment	M_{e1} [kNcm]	1186.55
Stress concentration factor	S_{k1}	1.13
Equivalent stress at outer surface	$\sigma_{e,out1}$ [kN/cm^2]	6.63
Equivalent stress at inner surface	$\sigma_{e,in1}$ [kN/cm^2]	3.32

Table 3. The results of equivalent stresses at section S2 of hollow axle

Equivalent moment	M_{e2} [kNcm]	2646.92
Stress concentration factor	S_{k2}	1.54
Equivalent stress at outer surface	$\sigma_{e,out2}$ [kN/cm^2]	10.15
Equivalent stress at inner surface	$\sigma_{e,in2}$ [kN/cm^2]	5.53

Table 4. The results of equivalent stresses at section S3 of hollow axle

Equivalent moment	M_{e3} [kNcm]	7449.98
Stress concentration factor	S_{k3}	1.00
Equivalent stress at outer surface	$\sigma_{e,out3}$ [kN/cm^2]	16.13
Equivalent stress at inner surface	$\sigma_{e,in3}$ [kN/cm^2]	8.44

Table 5. The results of equivalent stresses at section S4 of hollow axle

Equivalent moment	M_{e4} [kNcm]	6351.16
Stress concentration factor	S_{k4}	-
Equivalent stress at outer surface	$\sigma_{e,out4}$ [kN/cm^2]	13.75
Equivalent stress at inner surface	$\sigma_{e,in4}$ [kN/cm^2]	7.20

The overview of obtained equivalent stresses in the considered sections of the hollow axle is given in the Table 6.

Table 6. The overview of obtained equivalent stresses in the considered sections of the hollow axle

Section	Equivalent stress	
	$\sigma_{e,out}$ [kN/cm^2]	$\sigma_{e,in}$ [kN/cm^2]
S1	6.63	3.32
S2	10.15	5.53
S3	16.13	8.44
S4	13.75	7.20

The obtained results should be compared with the corresponding permissible stresses that depend on the axle material and location of considered section. The permissible stresses for a given axle material and considered section are determined on the basis of the endurance limits and the corresponding safety factor.

5. CONCLUSION

The methodology for analytical calculation of strength of hollow axles of railway vehicles in accordance with international standard EN 13103 is exposed in the paper. The whole procedure is demonstrated on the concrete example of hollow axle for normal track gauge of 1435 mm and 25 tons of axle load. As expected, the most critical section of the considered axle is section S3 near to the pressed joint between wheel and axle, oriented towards the middle of the axle. The obtained results of the equivalent stresses should be compared with the corresponding permissible stresses that depend on the axle material and location of the considered section of hollow axle. The exposed procedure can be useful for all those who deal with design and optimization of axles of railway vehicles.

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XX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
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EXPERIMENTAL AND NUMERICAL DETERMINATION OF THE FREIGHT WAGON BUFFERS CHARACTERISTICS

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Saša RADULOVIĆ[3]
Goran SIMIĆ[4]
Vojkan LUČANIN[5]

Abstract *– Draw-buff gear plays a significant role in the transmission and damping of longitudinal forces generated during accelerating and braking of trains. The role of the buffers is to protect the railway vehicles bearing structure, cargo and passengers from excessive longitudinal impacts. Especially when shunting freight wagons. For that reason, they have built-in elastic-damping elements that absorb shocks and partially convert kinetic energy into heat. This paper analyzes buffers with rubber-metal springs, which are the most often used in the freight cars nowadays. The static and dynamic force-stroke characteristics obtained by measurements on hydraulic press and during buffing impact tests are presented. These results are then compared with calculations using FEM analyses. The analyses included checking of the buffers ability to absorb a sufficient amount of energy that can be generated during wagon normal operation and in the case of exceptional shunting impacts.*

Keywords – buffers, force-stroke characteristics, measurements, absorbed energy.

1. INTRODUCTION

The requirements that must be met by buffers for installation on railway vehicles are very extensive. They concern both the geometric characteristics of the buffers, the materials used, as well as the corresponding characteristics of the force-stroke they achieve during loading cycle. For different types of buffers, these requirements are specified in the European standard EN 15551:2016 [1]. This paper presents the determination of the characteristics of a 105 mm stroke freight wagon buffer with an elastomer-based elastic-damping element, i.e. rubber-metal springs [2]. Specific for elastomers, which are the most often type of material nowadays used in buffers of freight wagons, is that they combine elastic and damping properties.

Experimental measurements were performed statically on the press. While dynamic measurements were performed during buffing impacts of one freight wagon type Eanos on a tank wagon type Zacns at increasing speeds up to 12 km/h [3]. Considering that for exact numerical analysis were not available real material properties, obtained results of measurements served for determination of possible hypothetic constants of non-linear Mooney-Rivlin 2-parameter model, which give the best agreement with the experimentally obtained results [4, 5, 6].

The tested elastomeric elements TecsPak®, used in tested buffers, have been successfully produced by company Miner for many years [2].

2. BUFFER CHARACTERISTICS

The main role of the buffers is to reduce longitudinal shocks caused during accelerating, braking and shunting of the wagons. The characteristics of the buffer, depending on the rate of deformation, can be divided into static and dynamic. The static characteristics of the buffers, at low speeds of the buffer stroke, are significant when the vehicle passes through a curve, and during their initial preloading when forming the train composition. While the dynamic characteristics are valid for shunting impacts, as well as for longitudinal oscillations in the trains.

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Determining the static characteristics of the buffer is performed by loading the buffer on the press at a maximum speed of 0.05 m/s [1]. The characteristic is obtained by measuring the stroke and the force that is set on the hydraulic press. The displacement transducers and force transducer located under the buffer are presented in Fig. 1.

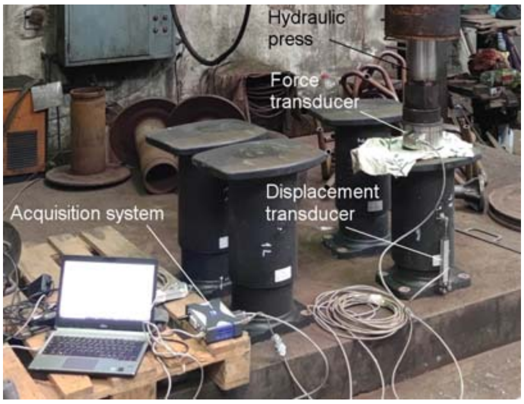

Fig.1. Measurements of buffers static characteristics [3]

Static energy capacity or stored energy during compression stroke must be greater or equal to 12.5 kJ. At least half of this energy during the first load cycle must be absorbed. During the second third etc. full loading cycle, this energy has to be greater or equal to 42% of stored energy. Depending on a vehicle type, i.e. buffer category, buffers have different demands for energy capacity [1].

As for the dynamic characteristics of the buffer, it is necessary that during the compression stroke of 105 mm, dynamic store energy is at least 30 kJ and absorbed energy 60% of the stored energy [1].

The main goal is that the characteristics of the buffer should be such that at normal shunting speeds of up to 12 km/h, during buffing impact, forces and accelerations do not reach values higher than prescribed. In order to check whether the buffers in the assembly with the wagon meet these requirements, a buffing impact test is performed. This test, in addition to checking the forces and acceleration, checks the strength of the supporting structure of the wagon, as well as the bearing capacity of the connections of equipment, which is attached to the vehicle body.

Determination of the dynamic characteristic of the buffers is performed by simulating the shunting of wagons. For testing, it is necessary that both wagons are equipped with buffers of the same category. In this case, it is necessary that the buffers are of category A. One of the wagons is standing unbraked on a straight and level track. The second wagon, loaded with bulk material, up to a total mass of 80 t impacts a standing wagon. Impact is done at gradually increasing speeds up to 12 km/h 1, 3]. During the impact, the force between each buffer and end beam, as well as the stroke of buffers were measured (Fig. 2).

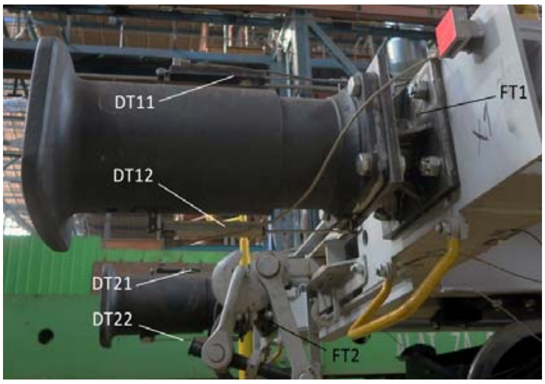

Fig.2. Measurements during buffing impact [3]

Diagrams in Fig. 3 represent measured buffers static characteristics for stroke 105 mm i.e. up to 1000 kN force. From the presented diagram can be seen that stored and absorbed energy during one load cycle meet requirements of the referent standard i.e. stored energy is about 40 kJ and damping coefficient is higher than 0.5.

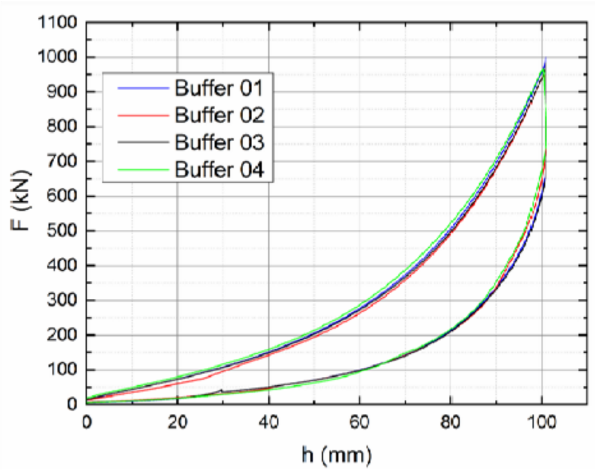

Fig.3. Buffers static force-stroke characteristics [3]

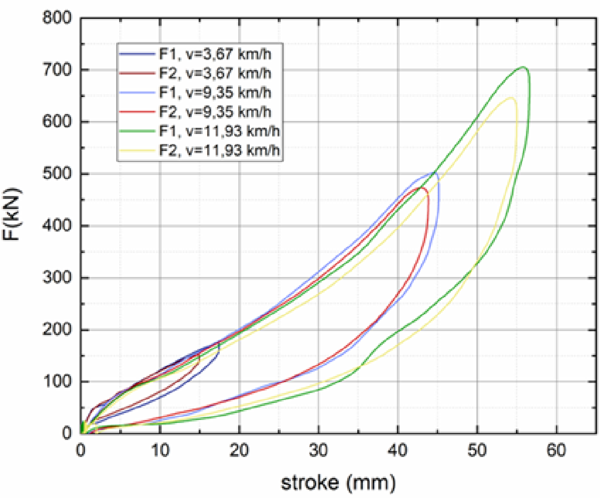

Fig.4. Buffers dynamic force-stroke characteristics [3]

Dynamic force-stroke characteristics for different impact speeds are presented in Fig. 4. Damping coefficient calculated for the recorded function is higher than 0.6.

3. NUMERICAL ANALYSES AND THEIR COMPARISON WITH TEST RESULTS

The rubber-metal element of the buffer is modeled according to the sample and the manufacturer's available drawings. Fig. 5 shows the complete buffer with spring. The numerical calculation was carried out in the Ansys software package.

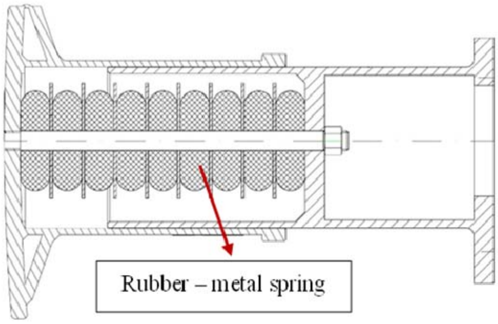

Fig.5. Category A buffer for stroke 105 mm [2]

Due to the reduction of computer resources required for simulation of the entire spring, the calculation was carried out with one segment pressed between two steel plates (Fig.6).

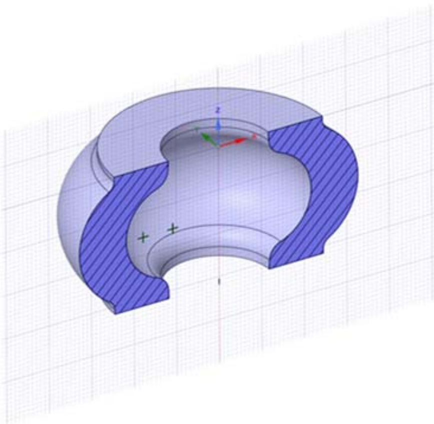

Fig.6. One elastomeric element of the spring

The 2-parameter Mooney-Rivlin hyperelastic material model was used.

Hyperelastic materials are characterized by nonlinear elastic behavior. They can withstand a large elastic deformation that is fully reversible after removal of the deformation strain. To describe a hyperelastic material, it is necessary to choose a specific model of material behavior, based on the deformation energy density W, whose exact representation is obtained experimentally obtained by simple strain tests, which include the following tests with specially prepared test specimens for: uniaxial, biaxial, pure shear and volume tests. Although these tests are performed separately and the stress states are different, the data from all the individual tests are used as one set to define the material model [4]. They cover different possible deformation cases and ensure a better agreement between the calculation results and the experiment. It should be emphasized that the test specimens must be made of the same material from which the elements whose characteristics we want to determine will be made [4, 5].

Since in this case we did not have the experimental results necessary to determine the constants of the Mooney-Rivlin model. With a combination of constants selected based on possible shear modulus and correlation with measured elastomer hardness, a numerical analysis was performed. Analysis results are presented in Fig.7 and Fig.8.

Fig.7 presents deformed element preloaded during assembling the buffer, plus deformed for buffers stroke of 105 mm. This deformation is reduced to represent of one of nine elements that form one spring.

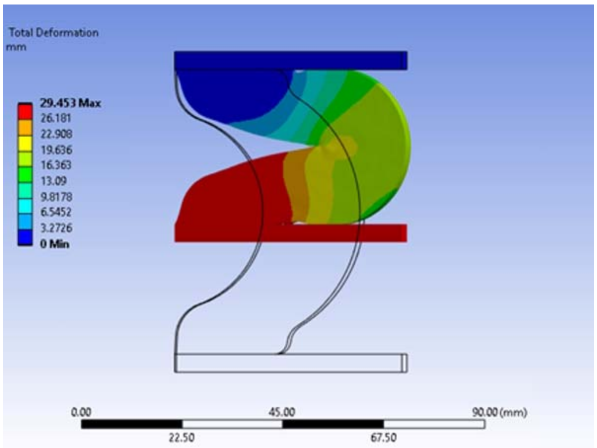

Fig.7. Deformation of one element corresponding to buffer stroke 105 mm

Fig. 8 presents static force-stroke diagram of one spring element obtained by numerical analysis.

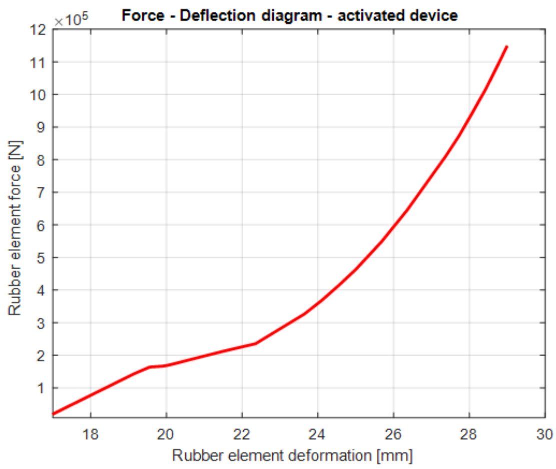

Fig.8. Buffers static force-stroke characteristics obtained by numerical analysis

Both diagrams, obtained experimentally and by finite element non-linear analysis are presented in Fig.9. Although there is fair well agreement between these two functions, it does not mean that material model will provide good results for other type of elements and parts subjected to different strain state and strain rate. This model and the analysis serve for better understanding of elastomeric material features and properties.

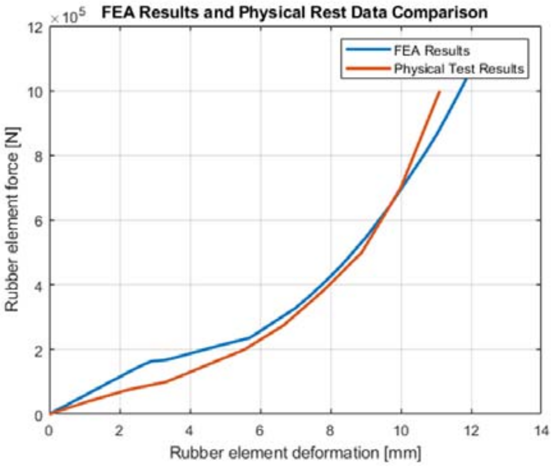

Fig.9. Comparison of the static force-stroke characteristics for one spring element obtained experimentally and by numerical analysis

4. CONCLUSION

Rubber-rubber springs are often used as an elastic-damping element of the buffers. Their force-stroke characteristics important for longitudinal dynamics of train and protection of vehicles bearing structure, cargo and passengers from excessive longitudinal impacts can be obtained by measurements but also by numerical simulations. By choosing the appropriate parameters and creating a numerical model based just on the knowledge of material hardness, it is possible to do it approximately. More detailed and precise analysis requires performance of material tests under simple strains, with special test specimens. Recorded sets of curves serve as input parameters of the material model. Nonlinear calculations in the large deformation’s domain, with such material models, enable easier optimization of parts made from elastomers and selection of desired elasticity characteristics.

ACKNOWLEDGEMENT

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TESTING OF RUNNING SAFETY OF RAILWAY VEHICLES IN ACCORDANCE WITH INTERNATIONAL STANDARDS

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Milan BIŽIĆ[2]

***Abstract** – This paper shows the methodology of experimental testing of running safety of railway vehicles in accordance with international standards. The special attention is concerned to the track quality for testing of dynamic behavior of railway vehicles. The problems of sampling frequency and signal processing are analyzed and discussed. The results of testing of the dynamic behavior of wagon for cars transportation in accordance with exposed methodology are presented and discussed.*

Keywords – Running safety, Dynamic behavior, Railway vehicles.

1. INTRODUCTION

One of the main aims on the railway is to increase the ride comfort and safety and security. The assessment of the dynamic behavior of railway vehicles is based on two criteria – testing the safety against derailment and testing the quality of ride comfort. Initially, it was considered that these two criteria were in absolute correlation, i.e., that a high level of ride comfort leads to high safety against derailment. This led to the development of a railway vehicles testing methodology that combines both criteria.

The most common and longest in use is the Sperling criterion [1], which is defined by UIC regulations. According to this criterion, the quiet running is determined by accelerations of the vehicle in the horizontal and vertical direction ($\ddot{y}$, $\ddot{z}$), impacts, i.e., changes in acceleration in time ($\dddot{y}$, $\dddot{z}$), and work of oscillation ($y \cdot \ddot{y}$, $z \cdot \ddot{z}$). The parameter W_z, which determined the quiet running of vehicle according to the Sperling, was corrected with the factor of subjective passenger feeling [2]. Additional criterion for the assessment of the running safety of railway vehicles is based on the determination of the lateral forces *H* [3] at the height of the axle bearing is introduced (the Martin i.e., Prud 'Homme criterion) [4, 5]. This criterion is valid for speeds up to 120 km/h, while for larger speeds is mandatory to apply the criterion of the ratio of lateral and vertical wheel-rail contact forces *Y*/*Q* [6, 7].

The vast efforts of UIC, ERRI, research centers and individuals around the world are focused on improving vehicle design through improved dynamic testing. All this has greatly contributed to increasing the safety and comfort of driving, but insufficient attention has been paid to the quality of the track on which the tests are performed. This shortcoming began to be largely corrected only after the advent of UIC 518 [5]. In accordance with the above, this research is focused on the possibilities and limitations of the application of international regulations on the example of experimental testing of the dynamic behavior of wagon for car transportation DDam which suspension is based on the parabolic spring (Fig. 1).

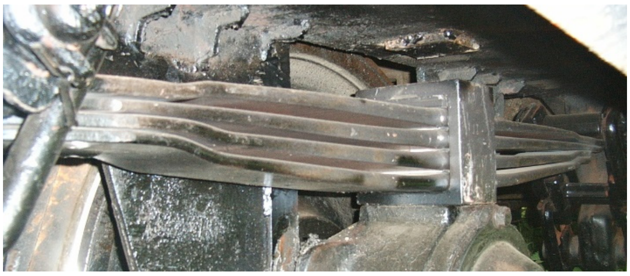

Fig. 1. The suspension of DDam wagon for cars transportation – parabolic spring

2. TRACK CHARACTERISTICS

In accordance to the UIC 518 and EN 14363, the track quality is determined by using the measuring wagon. For assessment of the track quality, measured vertical and lateral irregularities are used. Each measuring wagon has its own transfer function between the actual and measured state of the track. The transfer function depends primarily on the applied principle of measurement and distance of the axles of measuring wagon. Therefore, different measuring wagons give different results for the same track section. For this reason, the railway administrations of the countries that participated in the preparation of the regulations

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performed a comparison of their measuring wagons and as standard they chose the measuring wagon of Holland railway. Measurements of all other measuring wagons are corrected by the correction coefficients *k*, according to the expression:

$$\sigma_{z,y} = k \cdot \sigma_{NSz,y} \tag{1}$$

where $\sigma_{z,y}$ is standard deviation of the vertical σ_z and lateral σ_y track irregularities measured by another measuring wagon, while $\sigma_{NSz,y}$ is standard deviation of the vertical and lateral track irregularities measured by Holland measuring wagon.

This way provides comparability of the results of dynamic testing of the same vehicles on different tracks, and even different vehicles on different tracks. The UIC 518 defines the track quality according to the standard deviations of the vertical σ_z and lateral σ_y track irregularities. The track quality is classified into three categories: QN1, QN2 and QN3, where QN3=1.3·QN2. It is recommended that testing of dynamic behavior of railway vehicles should be performed on a commercial track where 50% of sections have quality better or equal than QN1, 40% of sections have quality between QN1 and QN2, and 10% of sections have quality between QN2 and QN3. If track quality exceeds the QN3 limit values, the results of dynamic behavior of the vehicle is not taken into account in these parts of the track.

In order to be able to analyze the test results, it is necessary to divide the selected track route into sections of the prescribed length ℓ_s. International regulations define the way in which the division into sections and zoning should be done (Fig. 2).

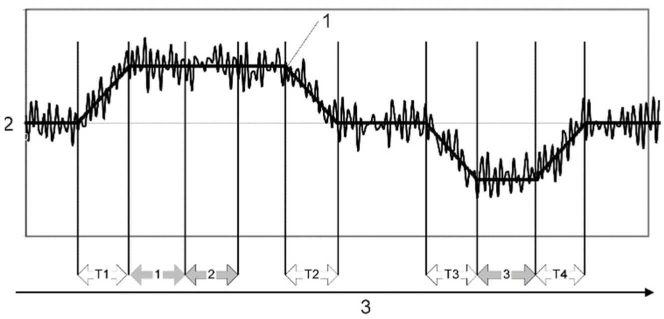

Fig. 2. Track sections in test zones for curved track

The meaning of certain labels in Fig. 2 is: 1 – curvature diagram, 2 – measuring value and 3 – track sections, separated in arc and transition curve. The minimum length of the section ℓ_s and the minimum required number of sections *N* is defined by UIC and EN regulations.

In order perform the analysis of the results of the test, in accordance with the standards it is necessary to divide the selected part of the track into sections of a certain length l_s and number *N*, and then assign them to zones that depend on the radius of the curve R, where distinguish: Z1 - zone of straight track (∞≥R≥2500 m); Z2 - zone of curves with large radius (2500 m>*R*≥600 m); Z3 - zone of curves with small radius (600m>*R*≥ 450 m), this zone is divided into the zone of full curves $Z3_k$ and zone of transition curves $Z3_p$; Z4 - zone of curves with very small radius (450m>R≥250 m), this zone is divided into the zone of full curves $Z4_k$ and zone of transition curves $Z4_p$; and Z5 – zone of point switch. The transition curves in statistical processing are separated from full curves. The individual length l_s and minimum number of sections *N* depend on the zone and are given in the regulations. The number of sections of transition curves and point switches is not defined by regulations.

3. TESTING OF WAGON FOR CARS TRANSPORTATION

The tests of the empty and loaded wagon were carried out on dry rails, on the following routes: Sid - Cuprija. The parameters being measured are shown in Fig. 3, where: H_I, H_{II}, H_{III} – lateral forces at the level of axle bearing on the first, second and third axle; $\ddot{y}_I$, $\ddot{y}_{II}$, $\ddot{y}_{III}$ – horizontal-lateral accelerations on wheelsets on the first, second and third axle; $\ddot{y}^*$ – horizontal-lateral acceleration of the car-body above the last wheelset; $\ddot{z}^*$ – vertical acceleration of the car-body above the last wheelset. The DDam wagon was loosely hooked and placed at the end of the composition, comosed still of the locomotive and the wagon laboratory (Fig. 4).

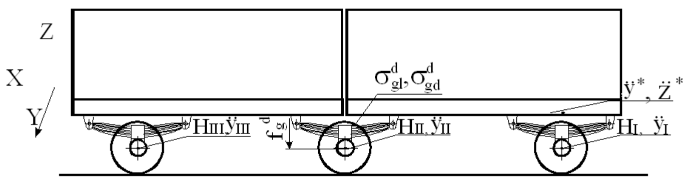

Fig. 3. Layout of measuring points at tests

Fig. 4. The position of tested wagon in composition

The limit values of the lateral forces $(H_{2m})_{\lim}$ measured at 2 m [9]:

$$\left(H_{2m}\right)_{\lim} = \beta \cdot \left(10 + \frac{P_o}{3}\right) \text{ [kN]} \tag{2}$$

where *Po* [kN] is axle load; β=0,75 is coefficient for empty wagon; and β=0,8 is coefficient for laden wagon. The limit values of lateral and vertical accelerations for freight and special wagons are:

$$\begin{aligned} \left(\ddot{y}_s^*\right)_{\lim} &= 4.43 - P_o / 140 \text{ [m/s}^2\text{]} \\ \left(\ddot{z}_s^*\right)_{\lim} &= 5 \text{ [m/s}^2\text{]} \end{aligned} \tag{3}$$

After measurement the load per axle, the limit values of lateral forces $(H_{2m})_{\lim}$, and the limit values of acceleration, for empty and loaded wagon, are calculated. The parameters related to the running safety are: $\left(\ddot{y}_s^*\right)_{\lim}$ – limit value of horizontal-lateral accelerations on the car-body; $\left(\ddot{z}_s^*\right)_{\lim}$ – limit value of vertical accelerations on the car-body; and $\left(s\ddot{y}_s\right)_{\lim}$ – RMS limit value of horizontal accelerations on the wheelsets [5].

The parameters related to the quiet running are: $\left(\ddot{y}_q^*\right)_{\lim}$ – limit value of horizontal-lateral accelerations on the car-body; $\left(\ddot{z}_q^*\right)_{\lim}$ – limit value of vertical accelerations on the car-body; $\left(s\ddot{y}_q^*\right)_{\lim}$ – RMS limit value of horizontal-lateral accelerations on the car-body; $\left(s\ddot{z}_q^*\right)_{\lim}$ – RMS limit value of vertical accelerations on the car-body; $\left(\ddot{y}_{qst}^*\right)_{\lim}$ – limit value of quasi-static horizontal accelerations on the car-body. The mean square deviation s of the statistical sample x of number N and mean value $\overline{x}$ is [6, 7]:

$$s = \sqrt{\frac{\sum_{i=1}^{N}\left(\overline{x} - x_i\right)^2}{N}} \tag{4}$$

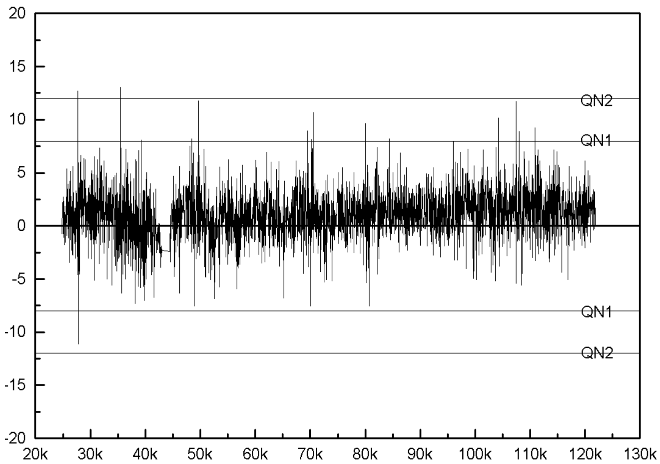

Fig. 5. Geometric characteristics of the track Šid – Nova Pazova – longitudinal level

On the test track with a slope of 1:20, the necessary measurements of the geometric characteristics of the track were performed with the test wagon of the Serbian railways. The processing of the recorded data was performed with the AP00 program and software developed at the Railway Vehicles Center in Kraljevo. The mentioned software is based on Instruction 339 on unique criteria for controlling the condition of railways on the Serbian railway network.

Permitted values of track quality QN1, QN2 and QN3 in the horizontal and vertical directions are defined by UIC 518 and are entered into the diagram records of the measured geometrical characteristics of the track (Fig. 5).

4. SIGNALS PROCESSING

The test means one continuous measurement, where the vehicle runs on geometrically different parts of the track (straight track, curves of various radii, transition curves and switches). One sample contains sections of one or more zones (Z1, Z2, …, Z5). In order to meet the defined minimum number of sections, the test of quiet running and running safety of DDam wagon was performed with several test runs. Statistical processing of recorded dynamic parameters is based on the regulation UIC 518, where the tests were divided into sections, then statistical processing was performed by sections and from them zones were formed where the final statistical processing was performed.

4.1. Processing by sections

Processing of measurement results is performed for each section separately. The length of one section ranges from 70 to 500 m. From individual measured parameters, for example $\ddot{y}^*$, when filtering, by applying different limit frequencies f_{gr} (which are defined by regulations), filtered values $\ddot{y}_s^*$, $\ddot{y}_q^*$ and $\ddot{y}_{qst}^*$ were obtained.

4.2. Processing per zones

The statistical values obtained by filtering in processing by sections x_i represents input data for processing by zones. In statistical processing by zones, for each value x_i, a mean value $\overline{x}$ and a mean square deviation s are determined. Finally, for each value by zones, a maximum estimated value $\hat{x}_{\max}$ is determined, using the expression:

$$\hat{x}_{max} = \overline{x} + k \cdot s \tag{5}$$

In the previous expression factor k has following values:

k=3 – for estimated values related to safety;
k=2.2 – for estimated values related to quiet running;
k=0 – for quasi-static estimated values.

Such determined maximum estimated value x is compared with the permissible value for each tested parameter, and the final assessment for the tested vehicle is made. Illustration of the obtained results is shown in the diagram on the Fig. 6.

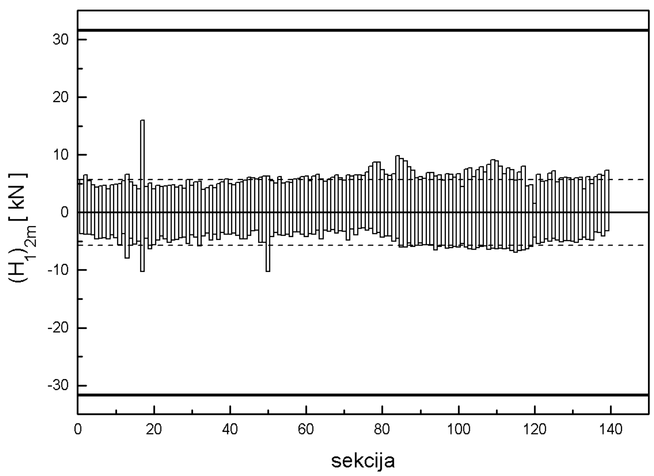

Fig. 6. Diagram of lateral force HI on the first axle determined for the zone of the straight track Šid-Nova Pazova - the movement of the empty DDam wagon at speed of V=130 km/h

5. CONCLUSION

An overview of the development of regulations related to the testing of the quiet running and running safety of railway vehicles is given. In UIC 518 special attention is paid to the quality of the track on which dynamic testing is carried out. From the requirement that tests should be carried out on a commercial track, it follows that the existing test polygons built for this purpose are excluded. Respecting the requirement for testing on a commercial track means even respecting construction regulations for the construction and maintenance of the track, which are different in some countries.

On the other hand, UIC regulations are international and valid in all UIC member countries. Therefore, it is necessary that in every country expert in the field of construction and mechanical engineering consider the possibilities of necessary harmonization. This is particularly related for requirement of UIC 518 regarding the cant deficiency and coefficients of the measuring wagons for testing the track quality.

The results of testing of DDam wagon are presented. The greatest difficulty during the preparation the tests was the selection of the track and the determination of its quality. In most cases, the condition of cant deficiency could not be met.

In addition, the organization of the tests required great efforts. The test was carried out on a commercial track at speeds that were 10% higher than the allowed speeds. As for the analysis of the obtained results, which are feasible in the existing conditions, it was concluded that the DDam wagon meets the criteria related to the quiet running and running safety.

ACKNOWLEDGEMENT

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STRUCTURAL ANALYSIS OF ROBOT FOR TRAIN UNDERCARRIAGE VISUAL INSPECTION

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Lazar STOJANOVIĆ[3]

Abstract *– This paper presents the structural analysis of the robot chassis for its operational loads during underframe inspection tasks. The static structural analysis was performed in order to determine the maximum values of stress, deformation and strain energy of the robot chassis preliminary design, with a goal of reducing of its mass based on analysis results. Due to functional, technical and operational requirements defined, it is necessary to lower the mass of the robot as much as possible to enable easier manipulation and transport, while maintaining the sufficient robot stiffness for its normal operation. The analysis of the robot chassis encompasses two load cases; the first load case checks the stresses and deformations due to the robot's own weight, and the second when the robot changes the direction of movement.*

Keywords – Static structural analysis, Unmanned Ground Vehicle, lightweight design, railway inspection robot.

1. INTRODUCTION

This paper presents the structural analysis of the AuTonomous Undercarriage Visual Inspection System (ATUVIS) robot chassis. ATUVIS is an TRL6 patent pending robotic solution [1] for railway vehicles underframe inspection. As the robot moves below the vehicle on rough terrain, due to sleepers and broken stone tamping, it is necessary to ensure satisfactory stiffness of the chassis against impacts, bending, twisting during movement and changes in direction of movement. The geometry of the robot during operation must not be compromised thus deformation of the chassis must be as low as possible to ensure sensors/actuators positioning and accuracy of sensor readings. Furthermore, the robot mass must be as low as possible to enable robot easy transport and manipulation. The given requirements are conflicting and must be solved during the design stage. The noted conflict can be solved by principles of lightweight design. Lightweight design is a development strategy, which aims to realize a required function with a system minimized mass under predefined boundary conditions [2]. Lightweight design is generally not self-perpetuating, but has to be justified against design requirements [3].

Lightweight design can be achieved in many different ways that include material substitution, design elements thickness reduction and change of shape of the parts, elimination of parts that do not contribute significantly to stiffness, without sacrificing the overall structural integrity or functionality. With ATUVIS robot chassis, the preliminary effort to decrease robot mass was made by material substitution i.e., by using Alumina alloy instead of steel.

The structural analysis checks the stresses and deformations of the lightweight chassis due to the robot's own weight. The structural analysis was additionally performed for a worst-case operational scenario which occurs when the robot is changing the direction of the movement. The additional load on the chassis is imposed when two wheels turn under the influence of torque on one side and the two opposite wheels at that moment are the supports around which the robot rotates. In the following work, the geometry of the robot, the method and materials used to analyze the robot and the results obtained are given.

2. GEOMETRICAL DESIGN

The assembly of the robot (Fig. 1) consists of two completely symmetrical platforms for moving the robot (1) with two wheels, and a platform for moving the camera (2) [4]. The chassis of the robot is made of standard and non-standard profiles obtained from

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metal sheets. The design of the 3D model of the robot chassis was performed in Sheet metal module of SolidWorks. The basic parameters used for bending sheets in the Sheet metal module are given in table 1. The bending radius values used for bending the preparation on the former and the die allowed the material to enter purely plastic bending. The total mass of the robot with all components is 53 kg, while the mass of the robot chassis is only 18 kg.

The connection between the chassis components is separable, with screw connection. This robot was designed with the goal of reducing the mass of the robot and making assembly simple with future changes possible and assembly. General dimensions are given in figure 2.

Tab. 1. Experimental K - factor

Thickness [mm]	Material	K
from 1.5 to 2	Al 6061 T6	0.395
3	Al 6061 T6	0.31

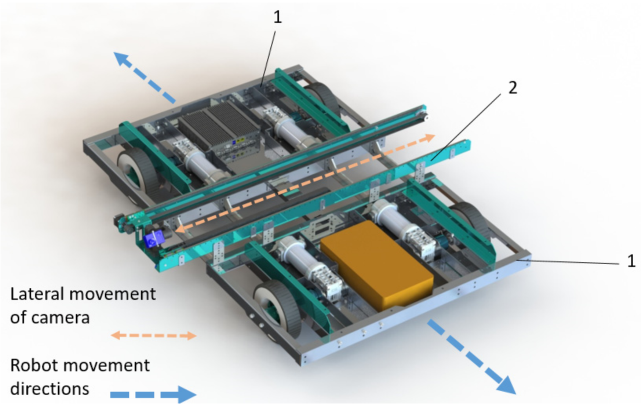

Fig. 1. 3D model of the robot

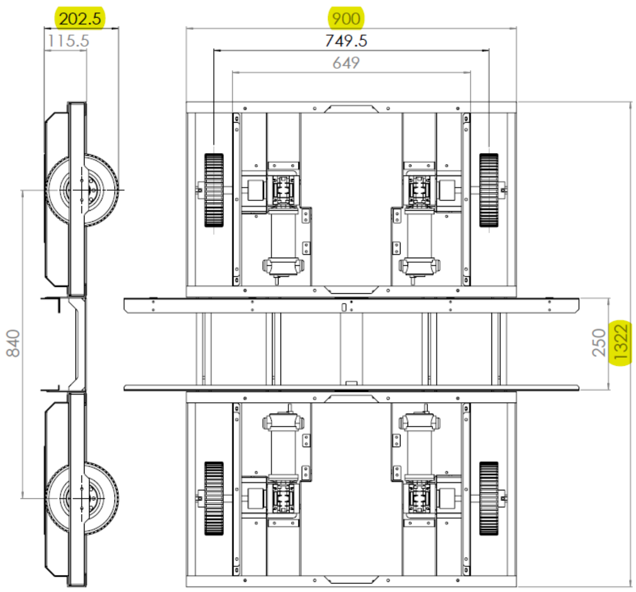

Fig. 2. General dimensions of the robot

3. METHOD AND MATERIALS

The method used to test stiffness and structural integrity of the robot chassis was structural static analysis by the finite element method. The analysis was performed in Ansys Workbench 19.2 software package [5]. Static analysis was used to calculate the effects of static loading of the chassis of the robot, with inertial force of gravity was also taken into account. Testing the structural integrity of the chassis robot using the finite element numerical method aimed to check robot chassis before manufacturing the robot itself.

Materials which are used in design were: Aluminum Alloy 6061-T6 for all chassis profile components, structural steel for components such as shafts, rim flanges, pivots, then ABS plastic for wheels. Table 2 defines the mechanical characteristics of the materials used in the analysis.

Tab. 2. Material properties

Aluminium Alloy 6061 T6	**Value**
Tensile Yield Strength	259 MPa
Tensile Ultimate Strength	313 MPa
Density	2710 kg/m3
Young's Modulus	68300 MPa
Poisson's Ratio	0.33
Structural Steel	**Value**
Tensile Yield Strength	250 MPa
Tensile Ultimate Strength	460 MPa
Density	7850 kg/m3
Young's Modulus	200000 MPa
Poisson's Ratio	0.3
ABS plastic	**Value**
Tensile Yield Strength	41.4 MPa
Tensile Ultimate Strength	44.3 MPa
Density	1040 kg/m3
Young's Modulus	2390 MPa
Poisson's Ratio	0.399

4. ANALYSIS CONDITIONS

The static structural analysis is divided into two load cases; first analysis (case 1) is analysis of the structural integrity of the robot chassis due to its own weight and weight of components (battery, industrial computer etc.). Second load case (case 2) is the analysis of chassis structural integrity due to rotation of two wheels on one side while the other two wheels are fixed, while considering friction between the wheels and the surface base. The second load case correspond to change of movement direction of ATUVIS robot.

Figure 3a, the loads and boundary conditions for load case 1 is shown. The mark H indicates the fixed support condition of the support surface, the forces marked D,E,F,G act vertically downwards in the middle of the platform for the movement of the camera, while the value of the individual force is 10N.

The forces marked B, C act on the middle of the platform for the movement of the robot and they individually amount to 50N. In case 2, in addition to the specified loads in case 1, the torques marked I, J on the wheels are added as shown in Figure 3b. The torque value is 25 Nm Which corresponds to maximal drivin motor torque. The frictional contact between the wheels and the ground shown in Figure 4. The friction coefficient is considered as 0.5 for the contact of wheels with the ground. The gravity force marked with A was also considered during the analysis.

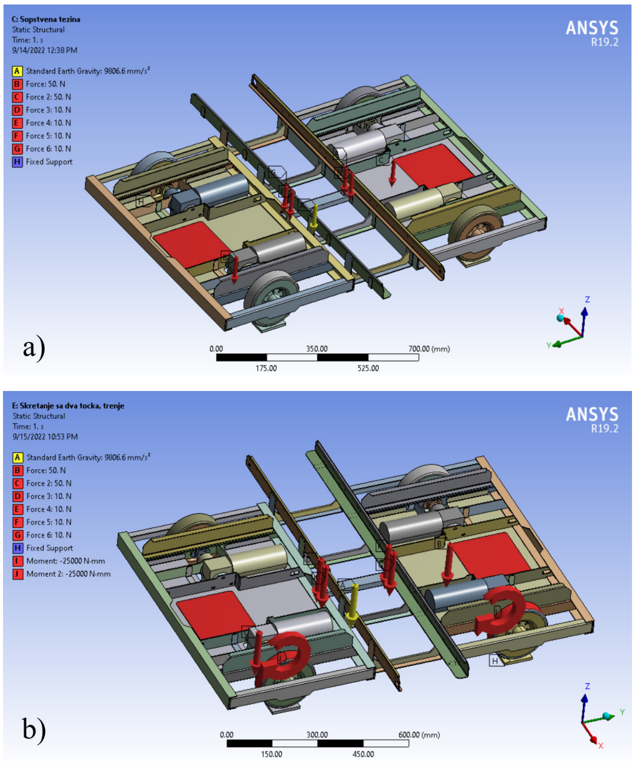

Fig.3. Boundary condition and chassis load for Case 1 and Case 2

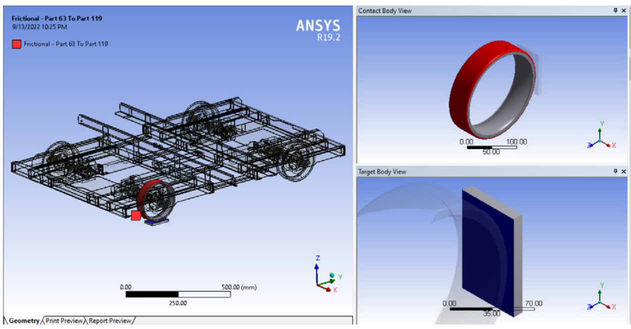

Fig.4. Frictional contact between the supporting surface and the wheel

The meshing was performed with 3D [5] higher order elements in order to exactly capture the geometry of some of the design elements as well to increase the accuracy of simulations. Maximum mesh skewness of the model was 0.8 which proves mesh quality and thus provides confidence in simulation results. The model consists of 1170615 nodes which form 594433 finite elements. A mesh size sensitivity test was performed to obtain confidence in accuracy of finite element simulations. It was assumed that the simulation results are insensitive to mesh size if the difference in equivalent stress and total deformation in two adjunct meshes is below 5%. The model finite element mesh iz shown on Figure 5. Face sizing was done on the contact surfaces where the frictional contact between the elements exists.

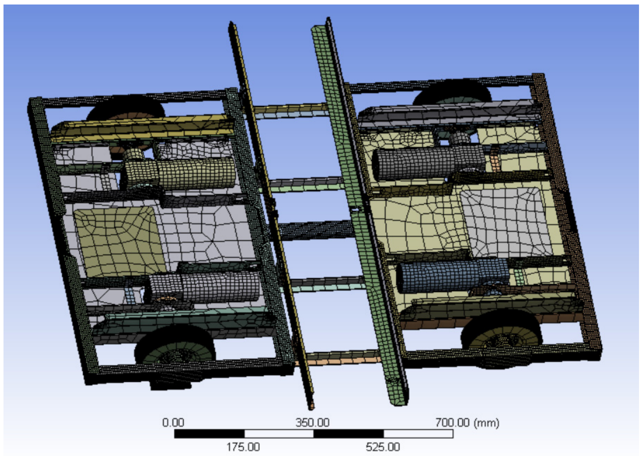

Fig. 5. FEM model mesh

5. RESULTS AND DISCUSSION

The first analysis (load case 1) on vertical bending strength showed that the robot chassis has good structural integrity.

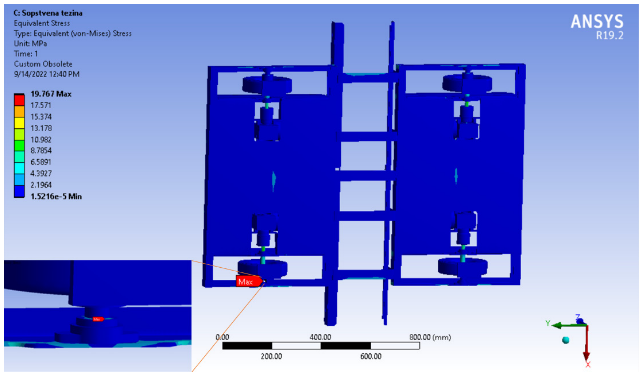

Fig.6. Stress distribution of robot chassis Load Case 1

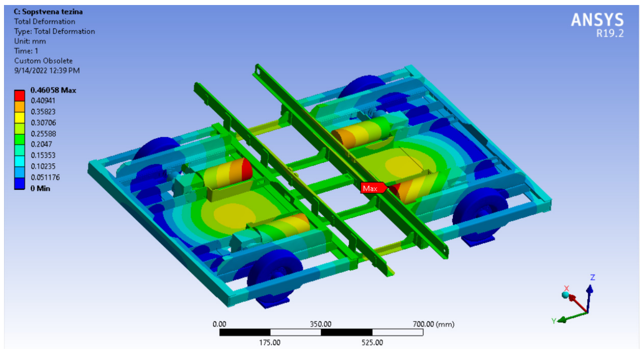

Fig.7. Deformation distribution of robot chassis Load Case 1

The maximum equivalent stress (Fig. 6) occurs on the shafts and it amounts to approximately 20 MPa which is considerably bellow yield strength of the materials used. The maximum value of Total Deformation (Fig. 7) that occurs on the chassis of the robot is 0.46058 mm which will not sufficient to introduce movement difficulties in linear robot joints and tho influence positioning accuracy.

The second analysis (case 2), which deals with testing the structural integrity of the robot chassis due to the load when the robot turns with two wheels while the other two wheels do not turn but due to friction between the wheels and the surface, shows that the maximum Equivalent Stress (Fig. 10) is the highest and is approximately 93MPa. Directional deformation in the vertical direction is also the largest and it amounts to 0.8 mm.

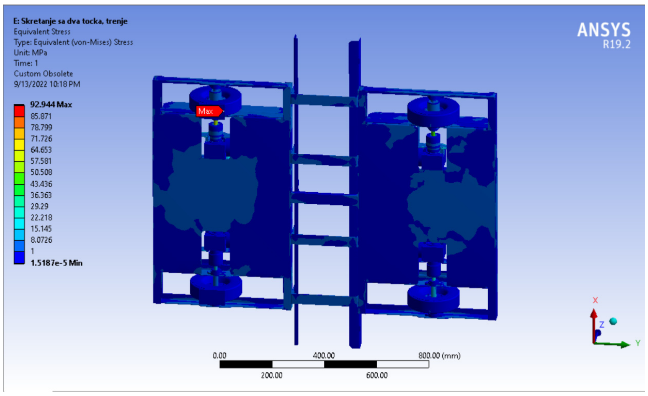

Fig.10. Stress distribution of robot chassis Load Case 2

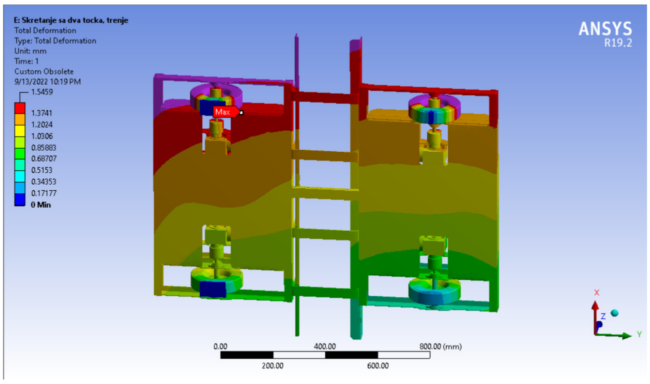

Fig.11. Deformation distribution of robot chassis Load Case 2

Figure 11 shows the distribution of total deformation for the load case 2, i.e., when the robot is changing the direction of its movement.

Table 2 summarizes the results for both load cases.

Tab. 2. Results of static structural simulation

Load Case 1	*Max. value*
Equivalent Stress [MPa]	19.767
Strain Energy [mJ]	0.1555
Directional Deformation Z axis [mm]	0.21534
Total Deformation [mm]	0.46058
Load Case 2	*Max. value*
Equivalent Stress [MPa]	92.944
Strain Energy [mJ]	0.83171
Directional Deformation Z axis [mm]	1.8466

6. CONCLUSION

Based on the obtained results, it can be concluded that the chassis of the robot in all load cases has sufficient structural integrity. Stresses are lower than the yield strength of the material used for design of the robot chasis, which indicates an optimal design of the chassis. The maximum stress on the chassis is 93 MPa, while the tensile strength for the aluminium material Alloy 6061 T6 is 259 MPa, which indicates that the safety level of the chassis is more than 2.5. The future direction of research would be to further optimize the chassis of robots and reduce their mass.

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XX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
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RESEARCH OF DYNAMIC PROPERTIES OF A LIGHT ROAD-RAIL VEHICLE UNDER OPERATIONAL CONDITIONS

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Abstract *– Railway transport is a very important part of a transport system not in European countries, but also in other regions. Except for the main transport means of railway transport, such as locomotives, wagons (passenger, freight), there is necessary to have available, which allow to maintenance of railway infrastructure. Road-rail vehicles belong to these transport means. In principle, road-rail vehicles are universal vehicles, which can operate both on roads and on railway tracks. They are modified from a road vehicles (lorries) in such a manner, that a chassis of a road vehicle includes an additional attachment. An attachment is mounted from the bottom part of a lorry chassis. In case of a need, the road-rail vehicle is able to use it and moves by means of it on a railway track. Then. a lorry equipped with the attachment can be used mainly for railway tracks maintenance. This paper is focused on analysis of dynamic properties of a light road-rail vehicle. It is derived from an existing light lorry. As the vehicle is considered as an idea, it is necessary to investigate its running properties on a track. The dynamic analyses are carried out in a multibody software. Analyses are performed for various running speeds and the main dynamical outputs, such as vertical wheel forces, lateral wheel force and derailment quotient. These outputs are important in term of running safety of the road-rail vehicle.*

Keywords – Road-rail vehicle. Multibody system. Dynamic analysis. railway track.

1. INTRODUCTION

Road-rail vehicles are in the railways field very important machines with their specific characteristics and properties. They are connected with both design and usage. They such are vehicles, which are able to operate on roads, and, after modification of chassis part, they are able to operate railway tracks. In these days, there can be seen these machines still more often, because they progressively replace older traction vehicles as well as track maintenance machines [1].

In term of driving properties of road-rail vehicles, there is important to ensure a sufficient contact of rail wheels of a vehicle chassis with rails. It is because as it is known, in case of rail vehicles, the rails both support and guide a vehicle on a track. In the contact of a wheel and a rail are generated forces [2-4], which have to be taken into account in the case of any modification of vehicles to be operated on railway tracks.

2. A MODIFICATION OF A MULTICAR M31 VEHICLE TO A ROAD-RAIL VEHICLE

A Multicar M31 represents a smaller and lighter versatile lorry, which is currently produced in Germany. This vehicle disposes with a wheelgauge of

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1327 mm. Generally, it can be used for transport of material. However, it has a SWV500 device for quick changing of attachments. These attachments can be applied during individual year seasons and may working activities can be performed. The basic superstructure of this vehicle is a tipping superstructure (Fig. 1).

Fig.1. A view of a Multicar M31 vehicle with a tipping superstructure

locations, where a road is approximately in the same level as a railway track, i.e. practically on every railway crossing. However, these places have to be large enough to steer the vehicle into the longitudinal position with the railway track. This is other advantage of the designed vehicle, because thanks to its small dimensions, in principle, there are not any limits and it can be performed anywhere.

3. MULTIBODY SIMULATION OF A ROAD-RAIL VEHICLE ON A REAL TRACK

Simulations of the road-rail vehicle by means of computational software have been performed. The simulations have been performed in the Simpack software package. The model consists of rigid bodies, which are interconnected by means of massless flexible elements [5, 6]. These flexible elements are mainly components of suspension systems, like dampers, springs, further spring-damping components of tyres etc.

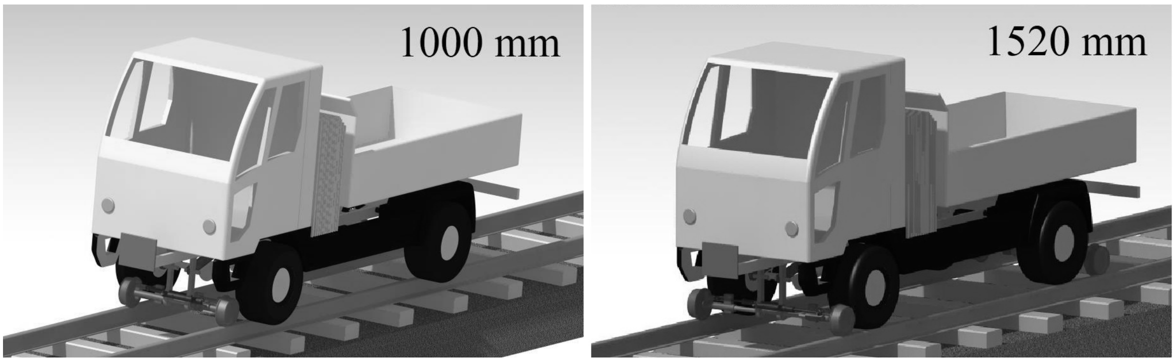

Fig.2. A visualization of a Multicar model with a tyre-rail adapter

This Multicar vehicle has been selected because of its a smaller wheelgauge and smaller vehicle contours, which are necessary to use it also on narrow railway tracks, which have a track gauge of 1000 mm.

The designed road-rail vehicle includes two adapters. One of them is mounted in the front part and the other is located in the rear part of a chassis. These adapters have three various positions for various track gauges and the wheelgauges is changeable depending on the request to the wheelgauge. These positions of adapters are changed, when a vehicle stands on tyres. In this position, adapters will be lifted and the total weight will be carried by the road wheels. For this vehicle design, controlling of adapters, i.e. lifting, adjusting and locking will be fully automatically from a vehicle cabin. It is really a considerable advantage of the system.

The designed road-rail vehicle with the designed adapter is visualized in Fig. 2. The left part of the figure shows the setting of the adapter for the track gauge of 1000 mm and the right part shows it, when it is adapted for the track gauge of 1520 mm. At the same time, these positions are the extreme positions of the adapters. The road-rail vehicle can be re-railed on

Regarding to mechanics, the multibody model of the road-rail vehicle is represented by the rigid bodies with defined masses, centres of gravity and moments of inertia [7, 8]. As it is mentioned above, other connecting elements are massless and they do not contribute to the weight of the individual bodies.

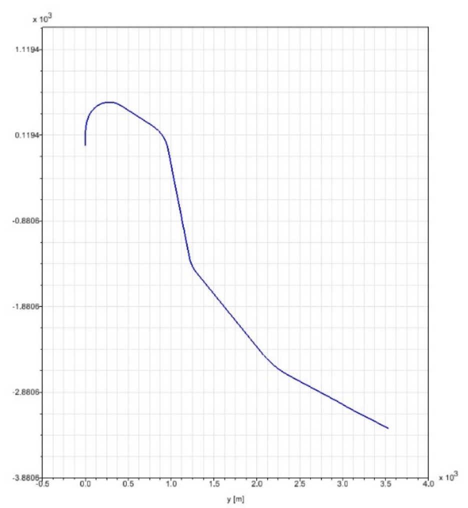

Fig.3. A visualization of a track geometry in a horizontal plane

A railway track is other important element in the computational multibody model, which is analyzed. In this case, the simulation computations have been performed with the road-rail chassis set for the normal track gauge, i.e. of 1435 mm. The simulation computations have been performed on a real track section, which it includes except of straight sections also sections with curves of various radii, superelevation ramps, transient sections etc. The rail head profile UIC60 and the rail cant of 1:40. There parameters are defined in the track input file. A view of the track in the horizontal plane of the railway track model is shown in Fig. 3.

The main goal of this investigation activities is to assess investigate the dynamical properties of the designed vehicle on a track. The main outputs parameters are quantities evaluated in the contact of a wheel and a rail. In the research, three main outputs have been evaluated, namely the vertical wheel force, the latera wheel force and the derailment quotient. These parameters have been assessed for the first axle (or the wheelset) in the running direction. The vertical wheel forces are marked as Q, the lateral wheel forces as Y and the derailment quotient is their ratio (Y/Q).

The results of performed simulation computations are shown in Fig. 4. This figure includes three sections for individual wanted quantities. The right wheel of the first axle is marked as 11 and it is represented by the darker curves (Fig. 4) and the left wheel of the first axle is marked as 12 and it is depicted by the brighter curves (Fig. 4).

As we can identify, when the vehicle runs in curves, the outer wheel is loaded by the higher force (the first curve in the running direction is a right curve). In the curve with a smaller radius (the left-hand curve, the section in Fig. 4 approx. 180s to 200

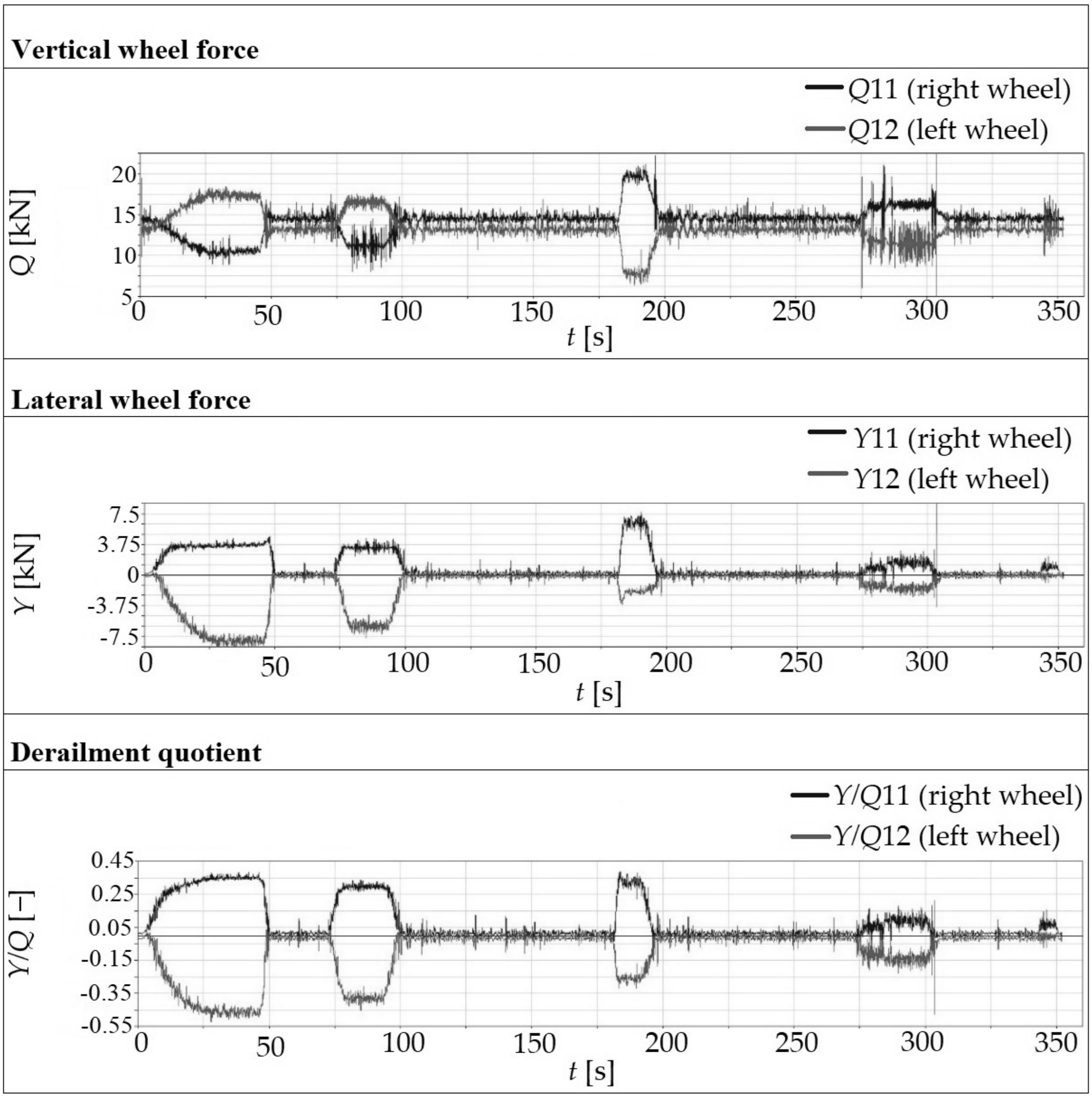

Fig.4. Waveforms of vertical and lateral wheel forces and a derailment quotient

s), the wheel forces reached the highest values about 20 kN. In the straight sections (Fig. 4 – sections 50 s to 75 s, 100 s to 180 s, 200 s to 275 s and 310 to 340 s), the vertical wheel forces correspond to the gravitational forces on the wheels.

The lateral forces are shown in the middle part of Fig. 4. These waveforms indicate, that the lateral wheel forces also arise when the vehicle is running in curves. It is caused by the reason, that wheels are loaded by the centrifugal forces in the curves. In the straight sections, the lateral forces are very small, closed to zero values.

The last evaluated parameter is the derailment quotient. It expresses the ration of the lateral and vertical forces. The derailment quotient should be under the value of 0.8 and in the smaller curves under the value of 1.2. As it can be seen, in the investigated cases, the derailment quotient does not exceed the value of 0.5. It means, the operation of the designed road-rail vehicle is for the track gauge of 1435 mm safe.

4. CONCLUSION

Road-rail vehicle are machines, which are widely used in the sphere of railway industry. Computer simulations belong to basic tools to analyze dynamics in term of driving and running properties.

Investigation of running safety is still a current problem and a distribution of forces in a contact of a wheel and a rail is very important. In this contents, there are mainly investigate vertical wheel forces in term of the track loads and lateral forces, which determine running safety in during movement in curves. After that, the ratio of lateral wheel forces and vertical wheel forces gives the derailment quotient, which the limit values are included in the specific standards.

In this research:

1. a road-rail vehicle with an additional chassis for running on a track has been designed
2. Simpack simulation software has been used simulation computation of the road-rail vehicle on a real railway track
3. a multibody model of a road-rail vehicle and a railway track have been created
4. there have been evaluated the dynamic forces, such as vertical wheel force and the lateral force as well as derailment quotient as a ratio of lateral and vertical wheel forces
5. there has been concluded, that the running of a road-rail vehicle in a curves leads to arising the vertical wheel forces as well as lateral wheel forces. The resulting derailment quotient similarly arise in curves. But, the reached values do not exceed the prescribed values in any cases

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XX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
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HOMOGRAPHY BASED DISTANCE ESTIMATION IN ATO SYSTEM

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Abstract *– In future decades, modern railway must offer cost-effective, flexible and attractive service for people and industry. However, it requires implementing many novel and modern technical solutions as Autonomous Train Operation (ATO), that lead to automation of railway transport. One of the most important parts of the ATO is a system for obstacle detection (ODS) that can detect obstacles on rail tracks and in their close vicinity in different light conditions. Furthermore, a key element of ODS is a system for estimation of distances between detected obstacles and train. In this paper, use of homography method for distance estimation in ATO system, was proposed. First, obstacles were detected on rail tracks and in their close vicinity using advanced image processing algorithm. Distance estimation was performed between camera stand and detected obstacles using the set of captured images, through mapping of points from real environment plane to the image plane. Results showed that proposed method can be used in ATO, but with certain limitations.*

Keywords – railway, automation, detection, obstacle, distance.

1. INTRODUCTION

Rail transport is a very important component in the daily transport of passengers and goods. With its capacity and complex infrastructure, it occupies an important place in business and everyday life. However, there are many safety challenges that affect the regular functioning of rail transport. On the railway infrastructure, i.e. the rail tracks, objects that might be an obstacle can be found, and that can lead to a slowdown or complete stoppage of traffic. From a safety point of view, level crossings are possible points of conflict and dangerous places due to crossing of rail, road, pedestrian and bicycle paths. In addition, the existence of any object on rail tracks and/or in close vicinity, represents a potential obstacle in safe railway traffic. Level crossings are illuminated, marked and equipped with appropriate equipment in the prescribed manner. However, unregulated crossings are not designed, marked and equipped with appropriate equipment or devices for safe traffic, and can be formed in unsecured places of railway infrastructure, so they represent dangerous places. In 2020, 1331 significant railway accidents were reported in the EU, with 687 victims and 468 people, who were seriously injured. In EU, the number of fatalities in railway accidents decreased gradually over the last decade, from 1 245 in 2010 to 687 in 2020. However, it should be noted that from 2019 to 2020, the decreases in railway accidents, fatalities and seriously injured people coincided with a sharp drop in passenger transport by rail caused by the Covid-19 pandemic. However, more than 50% of fatalities from railway accidents in the EU involved unauthorized people on the tracks (60%) and almost one third occurred at level crossings (31%) [1].

The basic idea of developing and implementing of autonomous systems in railway is to use certain level of automation in order to transfer operation tasks from the driver to the train control system. According to The International Electrotechnical Commission (IEC) standard 62290-1, Autonomous Train Operation (ATO) is part of highly automated system with reduced driver supervision [2]. The basic objectives of ATO are to improve the quality of rail freight in terms of punctuality, reliability and flexibility, to reduce the

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operating costs maximizing energy savings and resource efficiencies, to increase transport capacity on lines and hubs of the European TEN-T network and to make an important contribution to the vision of a fully automated rail freight system [3, 4]. However, the key element of ATO is Obstacle Detection System (ODS), that must obtain correct and timely obstacle detection obstacle on rail tracks and in their close vicinity, as well as distance estimation from train to obstacle, in different light and weather conditions. Given that visibility plays a key role, ODS must have different types of cameras due to different illumination conditions. In good light conditions, RGB cameras can be used. However, in low-light conditions and at night, visibility of objects can be reduced, and those cameras cannot give satisfactory results, so thermal imaging system can be adequate technical solutions.

In this paper, estimation of distance between setup with thermal imaging system and detected obstacles as a part of ATO system, was proposed. First, obstacles on rail tracks and/or in their close vicinity were detected using advance image processing algorithm performed on IR images. Then, homography method was used for estimation of distance between camera and detected obstacles. Results showed that homography based distance estimation can be used as a part of ATO, but with certain limitations.

2. EXPERIMENTAL SETUP

Within the research in SMART (Smart Automation of Rail Transport) project [5], detailed analyzes of possible technical solutions of the thermal imaging systems were performed [6, 7, 8]. Based on research results, the FLIR model TAU2 thermal imaging system with a resolution of 640 × 480 pixels and a lens with a fixed focal length of 100 mm (Fig. 1) was chosen as the optimal solution [9]. The small dimensions of the camera and the fact that the sensor does not require cooling, together with the ability to expand with an adapter for gigabit Ethernet communication, make it suitable for the needs of the capturing images at night and low-light conditions.

Fig.1. Thermal imaging system FLIR model TAU2: with lens (left) [9], without lens (right) [9]

Experiments were performed at night, in clear weather and at temperature of 8°C. The system shown in Fig 2. (left) was placed at the level crossing at the appropriate height, in order to simulate its position on train. This system, as in previous experiments, among other equipment, contains thermal imaging system and light sources that are positioned to simulate the presence of lighting devices in railway vehicles.

The chosen location for performing the experiments was the level crossing located near the village of Žitorađa, Serbia (Fig. 2 (right)). The level crossing is located in an uninhabited part or rural area, at the intersection of the local unpaved road and the main railway Niš-Prokuplje-Merdare. The experiments were performed on the part of the Niš-Prokuplje railway, between the Jasenica and Žitorađa-Centar railway stations, in the direction of Prokuplje. In that part, the railway is single-track and is not electrified. The level crossing is not marked with road signs, it is not illuminated, and it is not equipped with appropriate equipment or devices for providing safe traffic.

Fig.2. Thermal imaging system mounted at level crossing (left)

At named location, in daytime conditions with mostly sunny weather and a temperature of 4°C, the amount of illumination of 27,180 lux at the level crossing was measured, while along the rail tracks track it differed by ± 1%, on average. At night at a temperature of 2°C, the amount of lighting of 0 lux was measured at the entire location. The specificity of this location is that there are residential buildings at distance of 820 meters from the level crossing in the direction of Prokuplje and the local road about 50 meters from the crossing. Such a mixed environment is certainly a realistic scenario and can affect the operation of the ATO system.

3. OBSTACLE DETECTION

During the research, experiments with many scenarios were performed. Obstacle detection was obtained through five phases. First, a large number of IR images were captured by previously named thermal imaging system. For every image, process was same.

At first, rail tracks were detected using of Canny edge detector with optimal threshold. This was very important because not every detected object in scene represents an obstacle, so Region of Interest (ROI) must be determined. Detection of the objects was done by advanced image processing algorithm using the region-based segmentation with optimal threshold [10]. Finally, segmented image and original IR image was fused, and detected objects in ROI were marked as obstacles.

However, in presented scenario, four members of the SMART project team were at distance of 50 to 500 meters from the thermal imaging system. This is real world scenario and represents existences of different objects on rail tracks and/or in their close vicinity (Fig. 3 (left)). Based on detection and localization of rail tracks, ROI was determined and marked (Fig. 3 (right)).

Four objects were detected (Fig. 4 (left)) and marked with yellow rectangle as obstacles in determined ROI (Fig. 4 (right)). The analysis of the results shows that the detected objects are potential obstacles, but in the case of one object on the left track, only a part of it was detected. However, Fig. 3 (right) shows that this object is only partially in the ROI, so the detection of only one part of it is quite correct. Therefore, the results of the detection of potential obstacles in the scenario at this location are satisfactory.

Fig. 3. Obstacle detection scenario (left); Determined and marked ROI in IR image (right)

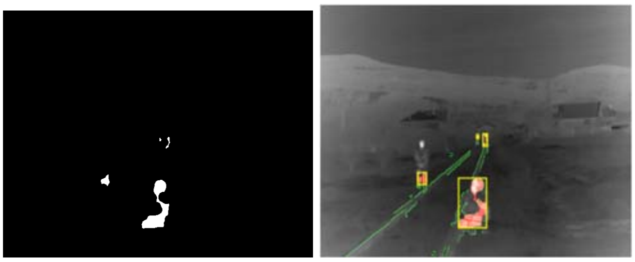

Fig. 4. Detected objects – segmented image (left); Marked obstacles in ROI (right)

4. DISTANCE ESTIMATION

Detection of obstacles is only one part of ATO system, while another should be estimation of distance between train and detected obstacle. This is very important due need to determine correct moment of starting braking process of the train, as well as braking force. Considering that ATO should be integrated in train, estimation of distance is performed between cameras and detected obstacles. In presented scenario, estimation of distance between experimental setup and marked obstacles in IR images is obtained using of homography method [11, 12].

In the first phase, calculation of homography matrix ***H*** was done by using four points – vertex of blue quadrilateral (Fig. 5 (left)). Coordinates of these points are known in real world and in IR image. The coordinates in real world were calculated based on experiment data, from known positions of people on rail tracks relative to the experimental setup, while coordinates in image are determined within an image. Calculated homography matrix ***H*** is given in equation (1).

*Fig. 5. Four points – vertex of blue quadrilateral for calculation of homography matrix **H** (left); Position of thermal imaging system on rail tracks (right)*

$$\boldsymbol{H} = \begin{bmatrix} 3{,}4875 & 0{,}188 & 26{,}1250 \\ 0 & 0{,}1364 & 949 \\ 0 & 0{,}0005 & 1 \end{bmatrix} \qquad (1)$$

In the second phase, homography matrix ***H*** was used for estimation of distance between middle of experimental setup and marked obstacles. Results of distance estimation is shown in Fig. 6, as follows: 52 meters (marked with red), 152 meters (marked with green), 373 meters (marked with yellow) and 572 meters (marked with pink).

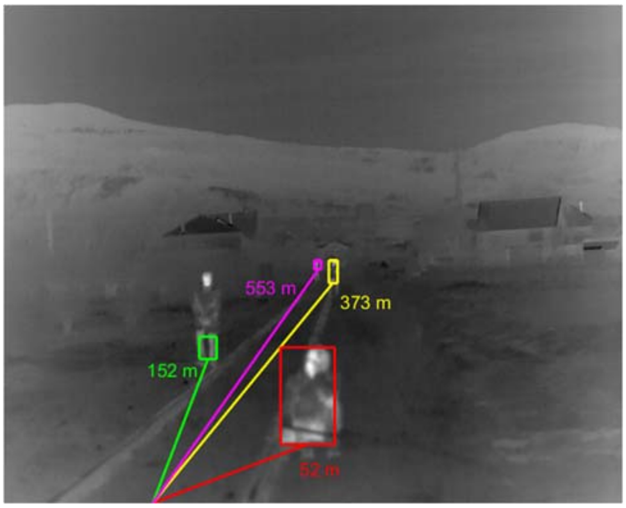

Fig. 6. Estimated distances between middle of experimental setup and marked obstacles

Validation of results is done within comparation of real measured distance, estimated distance using of homography method and estimation errors, shown in Tab 1. Estimation error increases with distance that is expected because of decreased accuracy of detection as well as accuracy in process of choosing points during the calculation of homography matrix. However, the maximum error is less than 10%, which represent satisfactory results.

Tab. 1. Validation of results

Measure No.	Measured distance [meters]	Estimated distance [meters]	Estimation error [meters]	Estimation error [%]
1.	50	52	2	4
2.	150	152	2	1.33
3.	400	373	27	6.75
4.	600	553	47	7.83

5. CONCLUSION

Modern railway must be competitive and sustain at the market, in order to survive many challenges. It is expected that in future decades, railway must be able to provide cost-effective, flexible, and attractive service to passengers and industry. However, it requires implementing new effective technical solutions that can decrease travel time and eliminate delays. On the other side, railway infrastructure is very complex because of its intersecting with other types of traffic. Because of that, there are many potentially dangerous places, where traffic accident can occur. Existence of any object on railway infrastructure can slow down traffic, or even stop. However, depending on illumination of railway infrastructure, not every object can be visible, nor obligatory represents an obstacle by its size and type, as well as distance from train.

This paper presents use of homography method for distance estimation in ATO system. The key element of ATO is Obstacle Detection System (ODS) that must operate in different illumination conditions. In order to operate in low light conditions and at night, thermal imaging system was used as a part of ODS system. Distance estimation was performed through next phases: capturing large number of IR images at night, detection of obstacles on rail tracks and in their close vicinity using advance image processing algorithm based on image segmentation, and distance estimation using homography method. Efficiency of proposed method was shown on scenario with four objects with mixed positions positioned on real distance in range 50-600 meters from experimental setup. Results showed that maximum error for distance estimation was 7.83%, which is satisfactory. However, accuracy of homography method mostly depends on quality of object detections, as well as of choosing points during the calculation of homography matrix. On the other side, great effect on low quality of object detections has quality of captured IR images, which can vary to the different weather conditions and used equipment.

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DEEP LEARNING-BASED RAIL TRACK DETECTION

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Abstract *– In this paper, a novel Deep Learning (DL)-based rail track detection representing a part of autonomous Obstacle Detection (OD) system for railways is presented. The OD system was developed within the project "SMART2-Advanced integrated obstacle and track intrusion detection system for smart automation of rail transport", which has been funded under the H2020-Shift2Rail-IA funding scheme.*

Keywords – Autonomous obstacle detection for railways, Deep Learning-based object detection, Rail track detection.

1. INTRODUCTION

To date, the majority of work regarding Obstacle Detection (OD) in railways has concerned static OD systems at level crossings that are one of the highest risk elements of the railway system as they involve the potentially unpredictable behaviour of road and footpath users [1]. However, an on-board OD system, which provides continuous monitoring of the rail tracks in front of the train using different on-board cameras (vision sensors), can complement the detection provided by static infrastructure such as level crossing monitoring systems, and so have the potential to significantly improve railway safety.

On-board OD in railways refers to the detection of objects on the rail tracks ahead of a running train that are potentially hazardous for the safe running of the train. Bearing this in mind, it is clear that on-board OD systems in railways shall consist of two consecutive steps: detection of rail tracks for the purpose of detection of image region of interest (ROI), and detection of objects in and near the ROI.

All, so far published methods for rail tracks detection using on-board cameras can be classified into two groups: traditional Computer Vision (CV)-based methods and Artificial Intelligence (AI)-based methods [2]. The methods from the first group use well-established CV techniques for both image segmentation (e.g., edge detection, corner detection or threshold segmentation), and for object recognition based on the extraction of so-called "hand-crafted" features. "Hand-crafted" features refer to properties extracted from an image (e.g., edges, corners, and shape descriptors of segmented image regions) using various methods that exploit the information present in the image itself. The AI-based methods in the second group are based on Machine Learning (ML) and in particular on Deep Learning (DL). In contrast to traditional CV methods that use "hand-crafted" image features to classify image areas as belonging to particular object classes, DL uses the concept of "end-to-end" learning of object detection. The latter is based on multi-layer artificial neural networks in which the machine (computer) is given a dataset of images that have been annotated with what classes of objects are present in each image of the dataset. Deep layers in these complex neural networks act as a set of generic feature extractors that are, to some extent, independent of any specific classification task. This means that a DL-based method results in a set of image features learned directly from the observations of the input images. These features are in literature referred as "non hand-crafted" features as opposed to those extracted by traditional CV methods [3]. Independently of the type of the method, a primary function of an autonomous vision-based on-board railway OD system is to detect and classify the objects at a certain range to avoid collisions and to determine potentially hazardous situations during the train operation. Bearing in mind that the objects that are hazardous to regular functioning of a train are those, which are on and near the rail tracks, a complete autonomous on-board system should include rail tracks detection besides the detection of objects.

In this paper, a novel AI-based method for rail tracks detection is presented. The main assumption for

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presented methods is that rail tracks are long objects consisting of number of connected parts that can be bounded with rectangular bounding boxes. Starting from this assumption, the presented rail track detection method uses a state-of-the-art bounding box DL-based object detection that detects parts of the rail tracks. For this purpose, the rail tracks in training images were annotated with multiple bounding boxes specifying rail tracks as objects consisting of multiple parts. Dealing with bounding box-based annotations and detection, the proposed rail track detection method is more efficient and faster than recent instance segmentation-based methods [4].

The rest of the paper is organized as follows. In Section 2, a comprehensive overview of related work on rail track detection from both groups, traditional CV-based methods and AI-based methods, is given. The proposed method for bounding box DL-based rail detection method is presented in Section 3.

2. RELATED WORK

2.1 Traditional CV Methods

The vast majority of algorithms for rail track detection that are based on traditional CV methods are geometry based. Starting from the rail track geometry as consisting of two parallel lines, several published works exploit methods for lane detection using the geometric characteristics specific to rail tracks. For example, the method proposed in [5] is based on the fact that the distance between the rails and other geometric details of the railway are known a priori for each country. In particular, the presented method uses the rail points that are also on a normal to one of the rails as the base markers for determining spatial coordinates as part of a Perspective-2-Point solution. The method for rail detection presented in [6] is based on three hypotheses: the gap between the rails at the initialization stage is constant, in the bird's-eye view, the rails are parallel, and, in the projectively distorted image, the rail tracks intersect in a vanishing point.

The geometry of rail tracks is exploited also in [7] in a method for rail tracks detection for determining the obstacle-free range for rail track maintenance vehicles. The presented method is based on projective transformation of the camera image into an image where the rails are parallel, and on tracking the two rail curves simultaneously by evaluating small parallel segments. The idea behind the projective transformation-based method is to get the so-called bird's-eye view of the rail tracks that is less distorted by perspective than an observer's view in the driver cabin of the train.

Some of the published papers present methods that are based on the extraction of specific rail track characteristics from the camera image such as their sharp edges that provide a large image gradient. For example, the authors in [8] present a railway tracks detection and turnouts recognition method that is based on extracting an image feature known as the Histogram of Oriented Gradients (HOG). First, HOG features are computed and the integral image is generated. After this, the railway tracks are extracted from the integral image using a region-growing algorithm. The method is based on the fact that the variance of the HOG features corresponding to the image blocks that contain rail track is relatively large since such a block always contains prominent edges.

In [9], gradient-based edge detection is used for rail tracks extraction. Extracted rail tracks are then tracked for the purpose of detecting rail switches. The authors in [10] present a method that detects the rails by matching image edge features to candidate rail patterns, which are modeled as sequences of parabola segments.

The performance of all of the traditional CV methods for rail track extraction mentioned above may deteriorate due to varying lighting conditions, change in weather conditions, and complex backgrounds. Traditional methods that use line or edge features to detect rail tracks may have a good performance in a fixed scene, but their performance may deteriorate fast as the scene changes. As a train travels along the track, the background is constantly changing, and the "hand-crafted" features of traditional CV methods may not be robust enough to meet the requirements. Because of this, recently, several AI-based methods using "non hand-crafted" features are proposed.

2.2 AI-Based Methods

AI-based rail tracks detection methods reformulate railway detection tasks from railway line detection or edge detection problems, as considered in traditional CV methods, to image segmentation problems. In [11], an efficient rail area detection method based on CNN was presented. The method consists of two parts, extraction of the rail area and its further refinement. The latter consists of maximizing the matching of the contour of the extracted rail area using a polygon fitting method, and thus getting a more accurate outline of the rail region. The presented CNN achieved rail area extraction at the pixel level of resolution. The used network was inspired by the commonly used segmentation network SegNet [12], an encoder–decoder architecture for image segmentation, which trades off detection precision and extraction efficiency and consists of an encoder to extract the features of the rail area in the image, and a decoder which upsamples the encoder's feature maps to match the input resolution and also classifies the rail track area in the image in a 'softmax' layer. The training and testing of the proposed network was done using a bespoke dataset named BH-rail, which was annotated according to Cityscape dataset standards [13], i.e., pixel level labeling for the rail region and the non-rail region was used. The dataset was recorded on the Beijing Metro Yanfang line and the Shanghai metro line 6 with an on-board RGB camera. The BH-rail dataset has 5617 annotated images and covers representative real scenarios including tunnel and elevated environments.

In [14], a DL-based segmentation algorithm for railways named RailNet is presented. RailNet is an end-to-end DL-based railway track segmentation algorithm that consists of a feature extraction network and a segmentation network. The feature extraction network uses a pyramid structure to propagate features from top to bottom to obtain a hybrid feature vector. The segmentation network is a convolutional network for generating the segmentation map of the railway. In order to train and test the RailNet network, the authors created the Railroad Segmentation Dataset (RSDS) that includes 3000 images, 2500 images for training, 200 images for validation and 300 images for testing. All of the images came from a real-world train's driving environment. In the ground truth labelling of the railway datasets, the railway was defined as all pixels between two rail tracks. The weights of the RailNet backbone neural network were initialized using weights trained by the publicly available large-scale ImageNet Dataset [15].

A rail detector based on an on-board thermal camera for detecting rails at long range and, in night conditions using machine learning and in particular using DL and a CNN, is presented in [16]. The developed CNN, a modification of a CNN already proven in other image classification applications, detected key points along the rails and put the largest weight on the area furthest away from the train. A labelled dataset for CNN training and testing was produced manually. The data were recorded by an on-board thermal camera mounted on the top of the locomotive. Recording was done during different times of the day, and four video sequences were used in the dataset. All the frames in these sequences were labelled, except for the frames containing multiple railway lines. The performance of CNN-based method for detecting key features on the rails was compared with the performance of a previous system from the same research group, which was based on a traditional CV method. The trial results demonstrated the capability of CNN-based methods for automatically learning rail features, in particular distant features that could potentially be used in place of "hand-crafted" features.

3. PROPOSED METHOD

As said in Section 1, rail tracks detection is an integrated part of Obstacle Detection (OD) in railways as it determines ROI within which the obstacles are searched for. The proposed rail track detection is based on a state-of-the-art bounding box DL-based object detection. More precisely, CenterNet [17] that is used for object detection in SMART2 system [18] is also used for the detection of rail tracks. For the purpose of training of CenterNet to detect rail track parts, 234 images with rail tracks in SMART2 dataset [18] were annotated so that the visible rail tracks were annotated with multiple bounding boxes. The number of bounding boxes used for annotation depended on the length of rail tracks in the image. An example of annotation of straight rail tracks with six bounding boxes (blue transparent rectangulars) is given in Fig. 1 (left).

Fig.1. (left) Annotation of rail tracks with multiple bounding boxes along the visible length of the rail track. (right) CenterNet detection result of detected rail track parts as marked with purple bounding boxes.

During the annotation process, when selecting the parameters of the annotation bounding boxes, the following criteria were applied:

- The bottom left and the bottom right corners of each bounding box have to lie exactly on the outer edge of the left and right rail track respectively;
- The ratios of height and width of the individual bounding boxes are approximately constant.

The 234 original images from SMART2 dataset were selected so that the annotated dataset contained diverse data: images with different backgrounds as captured in different weather and illumination conditions and images with different structure of rail tracks terrain. The CenterNet model, originally trained with COCO dataset [19], was retrained with annotated rail track images using the following hyperparameters: learning rate= 2.5e-4, number of epochs = 230, batch size = 4, learning rate drop at epoch 180 and epoch 210, and input resolution = 1024.

An example of the CenterNet model detection is given in Fig. 1 (right). As it can be seen, corner points of the bottom sides of all bounding boxes lie very precisely on the rail tracks, so that linear regression lines obtained by curve-fitting through these points represent the rail tracks reliably.

The left/right regression line is formed starting from the left/right bottom corner of the lowest bounding box in the image (y_{max} coordinate) to the left/right upper corner of the uppermost bounding box (y_{min} coordinate). Firstly, the average x- and y-coordinates of bottom corners of all bounding boxes, x_{avr} and y_{avr}, and the standard deviations, σ_x and σ_y, are determined. The correlation factor r is assumed to be 1 for the sake of simplicity. The slope of the regression line m can be determined using the equation:

$$m = r \cdot (\sigma_x / \sigma_y) \quad (1)$$

while the coordinates y_{max} and y_{min} for both regression lines are known through the coordinates of the bounding boxes obtained as the outcome of the CenterNet-based rail track detection, corresponding x-coordinates have to be calculated from the equation (2) for left regression line and (3) for the right regression line:

$$x_{max}=x_{avr} + (y_{avr}- y_{min}) / m;\ x_{min}=x_{avr} - (y_{max}- y_{avr}) / m \quad (2)$$

$$x_{max}=x_{avr} + (y_{max}- y_{avr}) / m;\ x_{min}=x_{avr} - (y_{avr}- y_{min}) / m \quad (3)$$

An example of calculated regression lines drawn onto the original image of rail tracks is given in Fig. 2 (left). As it can be seen, the calculated regression lines map the courses of the left and right rail track accurately so that they can be used for definition of region ROI within which obstacles are to be searched for. ROI are all pixels between the left and right rail regression lines as marked with green in Fig. 2 (right).

Fig.2. (left) Detected rail tracks represented by red lines overlied on the original image. (right) ROI represented as green transparent area.

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MECHANICAL AND STRUCTURAL PROPERTIES OF MIG WELDED JOINTS OF DIFFERENT ALUMINUM ALLOYS 2024 T351/6082 T6 IN PASSENGER TRAIN CAR BODIES

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Vladislav KRSTIĆ[5]

Abstract *– This paper presents the effects of MIG welding on the mechanical properties of a butt-welded joint of dissimilar aluminum alloys 2024-T351 and AA 6082-T6 on railroad cars. The aluminum alloy 6082 T6 is well weldable by the classical fusion welding processes (MIG and TIG), while the aluminum alloy 2024-T351 is almost not weldable. For the welding of these two Al alloys, the MIG welding method was applied to an 8 mm thick plate with the filler metal 4043A (AlSi5) and an argon-helium mixture as shielding gas. The evaluation of the mechanical properties of the welded joint of different Al alloys was performed by Vickers hardness testing, tensile and bending tests on the welded specimens. The influence of MIG welding on the microstructure of the welded joint was investigated by light microscopy (LM).*

Keywords – Welded joints of dissimilar aluminum alloys, AA 2024-T351, AA 6082-T6, MIG welding process, Microstructure.

1. INTRODUCTION

After steel, aluminum is the most commonly used metal. It belongs to the group of light metals. It is about three times lighter than steel. Aluminum structures are often used in transport engineering, automotive industry, railway industry, shipbuilding, aviation industry and even space technology. For the production of lightweight structures for transportation, various aluminum alloys are used, which have certain mecanical properties with low material density.

Constructions of cars, trains, ships, airplanes and spacecraft made of various aluminum alloys are usually joined by classical MIG and TIG welding processes, possibly also by friction stir welding, laser and electron beam welding. The material is well weldable if it is possible to make such a welded joint using a particular welding process that causes the smallest possible inhomogeneity in the weld that behaves well under all operating conditions (load, corrosion, high or low temperature, etc.) during the life of the welded material, product or construction. The weldability of aluminum alloys is affected by a number of factors: higher affinity for oxygen, resulting in a difficult-to-melt oxide; higher thermal conductivity and coefficient of thermal expansion; high shrinkage during solidification; and high solubility of hydrogen in the liquid phase, which decreases dramatically during solidification. When welding aluminum alloys, the mechanical properties in the heat affected zone (HAZ) decrease, the corrosion resistance decreases, pores and inclusions are formed, an oxidation layer Al_2O_3 is formed on the surface of the metal due to the high affinity of aluminum to oxygen, and cold and hot cracks appear. Aluminum alloys are welded with filler metals with increased Si or Mg [1].

If the technology of the welding process is not suitable, defects may occur in the weld metal area, reducing the reliability of the welded structure. Welding defects such as porosity, cracks, lack of penetration or lack of fusion may occur [2].

In this paper, investigations are carried out on the mechanical behavior of the welded joint by the MIG welding process between different aluminum alloys 2024 T351 and 6082 T6 using the filler metal S Al 4043A (AlSi5).

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2. EXPERIMENTAL PROCEDURE AND METHODS

Experimental research focused on determining the influence of the welding process MIG on the metallurgical and mechanical properties of welded joints of alloys 2024-T351 and 6082-T6. The 2024 aluminum alloy belongs to the 2XXX alloy series, whose main alloying element is copper. The mechanical properties of these alloys reach values similar to those of carbon steels. Copper increases ability of precipitation hardening due to creation of intermetallic phase $CuAl_2$. Precipitation hardening of this group of alloys occurs through the process of artificial aging. Alloys of the 2XXX series are generally poorly weldable by the classical fusion welding processes (MIG, TIG) because they are very sensitive to the occurrence of hot cracks and the dissolution of precipitate particles. Friction stir welding is mainly used to weld these alloys [4,5].

Aluminum alloy 6082 belongs to the 6XXX Alloys series, whose alloying elements are silicon and magnesium. These alloys are suitable for heat treatment (annealing, hardening, aging). Alloys of the Al-Mg-Si system have moderate strength and good corrosion resistance compared to other heat treatable Al alloys. Typically, these alloys have good formability and acceptable weldability.

The chemical and mechanical properties of alloys 2024-T351 and 6082-T6, which are the subject of this investigation and are bonded by the process MIG, are listed in Table 1. The chemical properties of the additional material used during welding are given in Table 2.

Tab. 1. Chemical composition and mechanical properties of aluminum alloy 2024 T351 and 6082 T6 [6]

	Mn %	Fe %	Mg %	Si %	Cu %	Zn %	Ti %	Cr %	Al %
6082 T6	0,4…1,0	0 … 0,5	0,6 … 1,2	0,7 … 1,3	0 … 0,1	0 … 0,2	0 … 0,1	0 … 0,25	Balance
2024 T351	0,65	0,17	1,56	0,046	4,7	0,11	0,032		Balance

	Yield strength min R_{eh}/MPa	Ultimate tensile strength min R_m /MPa	Elongation at Break min A / %	Hardness HV
2024 T351	310	425	10	137
6082 T6	260	310	10	95

Tab. 2. Chemical composition of the additional material of wire EN ISO 18273 S Al 4043A (AlSi5)

Mn %	Fe %	Mg %	Si %	Cu %	Zn %	Ti %	Be %	Al %
<0,15	<0,6	<0,2	4,5 … 5,5	<0,3	<0,1	<0,15	<0,0003	Balance

The dimensions of the plates used for welding were 300 mm long, 125 mm wide and 8 mm thick. Welding machine was Fronius Transpuls Synergic 4000. Shielding gas was ISO 14175 – I3 –ArHe–30.

Welded joint made with a backing material (Fig. 5). Specimens were cut from the welded samples using the waterjet cutting method. A Leica Q500MC optical microscope was used to analyze the microstructure of the welded joint. The microstructure was examined on the cross-section of the specimens after the usual metallographic preparation and etching with Keller's reagent.

3. RESULTS AND DISCUSSION

The joints without defects were used to prepare many specimens for mechanical test.

3.1. Static Tensile Test

Figure 1 shows the specimen after breaking.

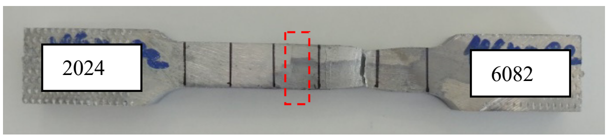

Fig. 1. Specimen after a static tensile test

The relationship between stress and strain during the tensile test is given in Figure 2, and the test result is shown in Table 3.

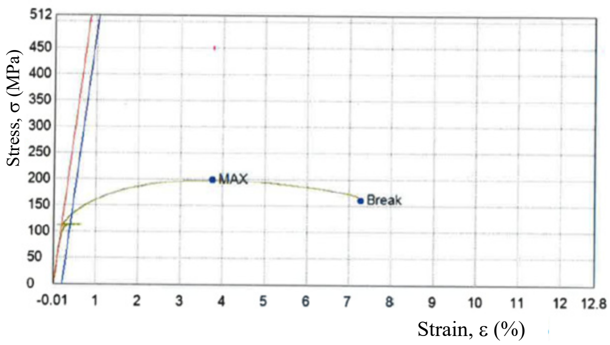

Fig. 2. Stress-strain diagram

Tab. 3. Tensile test results of welded joints

Cross-section area (mm^2)	Yield strength R_{eh} (MPa)	Ultimate tensile strength R_m (MPa)	Elongation at break A (%)	Place of fracture
80	113	198	7,3	BM 6082 T6

Hardness measurements were performed on base metals, weld metal and HAZ in two lines, as shown in Figure 3. Figure 4 shows the results of the measurements.

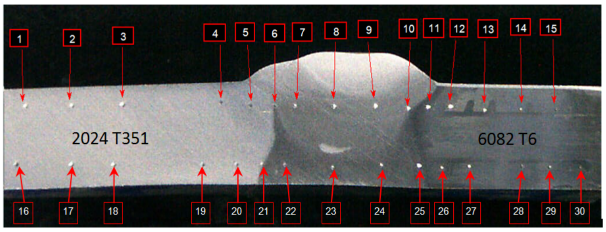

Fig. 3. Cross-section of the 2024 T351–6082 T6 aluminum alloys welded joint. Places of hardness measurement on the welded joint

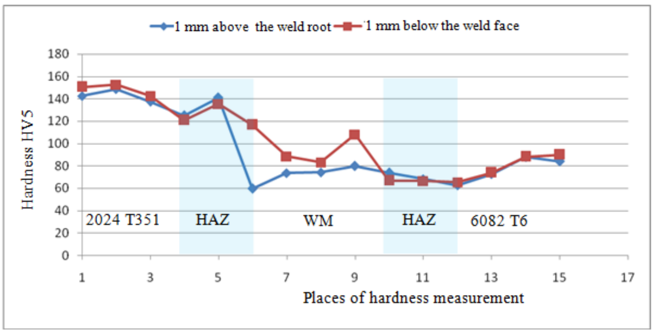

Fig. 4. Hardness distribution through a butt MIG welded joint of alloys 2024-T351/6082-T6

3.2. Macro- and Microscopic Examinations

Figure 5 shows the macrostructure of the weld in cross-section through the weld axis. The joint has a regular symmetrical shape with visible underfilling of the weld face, without visible pores.

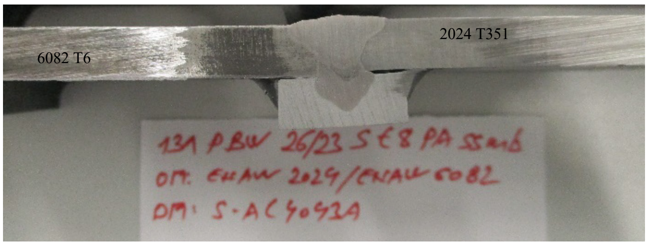

Fig. 5. Macrostructure of a welded joint made with a backing material

Figure 6 shows the microstructures of the welded joint in the base material zones, the heat-affected zones and in the weld metal. The microstructure of the base metal BM1 - aluminum alloy 2024-T351 - is shown in Figure 6a. Elongated grains were observed on the sample in the rolling direction. Fine precipitate particles are present.

Microstructure of BM2 - aluminum alloy 6082-T6, shown in Figure 6b. IMF can be seen on the sample in the form of larger particles in the rolling direction and fine precipitate particles formed during the aging process.

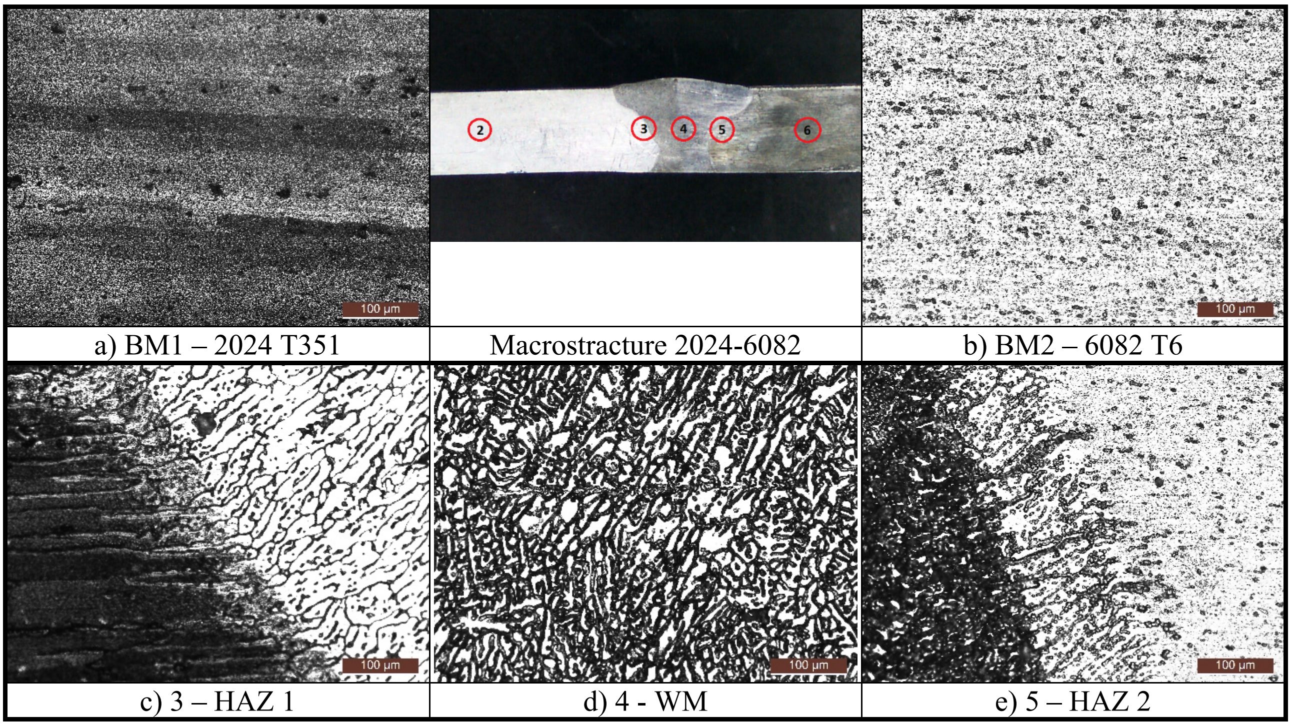

Fig. 6. Microstructure of the welded joint

The addition of heat causes the base metals and the filler metal to combine, creating a zone of weld metal with a structure different from that of the base metals. A higher silicon content (about 5%) in the chemical composition of the filler metal is useful to increase the ductility of the welded structure. The fusion zone or area of weld metal is created by filling a previously prepared groove with molten filler metal. After hardening, the weld metal exhibits a characteristic cast structure. The last hardening layer exhibits a pronounced dendritic structure characterized by the occurrence of liquefaction, i.e. local chemical inhomogeneity, due to the lack of time for the diffusion of the atoms of the alloying elements. Figure 6d shows the microstructure of the weld metal. Precipitate particles separated by grain boundaries can be seen. The grains are of different sizes and have a directional orientation, according to [7].

Figure 6e shows the microstructure of the HAZ between the weld metal and the 6082 T6 base metal. A narrow zone of columnar crystals can be seen at WM up to the HAZ. The precipitate is distributed along the grain boundaries and within the grain in a coarse form. The precipitate in the HAZ was randomly distributed in the form of spherical coarse particles. Figure 6c shows the microstructure of the HAZ between the weld metal and the base metal 2024 T351. In the HAZ, the precipitate is separated by grain boundaries. In the WM to the HAZ, the precipitate is separated by grain boundaries with a columnar orientation.

The fracture location of the specimen for the tensile test is located in the base metal - 6082-T6. The results of the bending tests indicate poor technological properties of the welded joints. A small bending angle to the appearance of a crack indicates that the welded joints are very brittle according to [7, 8, 9 and 10].

4. CONCLUSION

Based on the above, it can be concluded:

- The maximum tensile strength of the welded joint is (198 MPa) compared to (310 MPa) of alloy 6082-T6, which is a weaker welded joint material, i.e. the reduction in strength is about (36%).
- It was found that the fracture of the tensile specimen occurred on the 6082-T6 aluminum alloy side.
- The hardness of the weld metal is 55% lower than the hardness of the base material 2024-T351.
- To improve the performance of welded joints of different aluminum alloys 2024-T351 and 6082-T6, it is necessary to choose optimal welding parameters.

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Traffic and Transport

RAILWAY TIMETABLE ANALYSIS USING CRITICAL PATH METHOD

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Abstract *– Because of its complexity and comprehensiveness a timetable is one of the most significant documents at railway. Timetable production process is conducted manually, based on experientially defined principles, or, more frequently, through utilization of some developed computer tool. In any case, assessment of timetable quality is very difficult, as well as identification of those elements which could be used for the improvement, since the main criteria is timetable feasibility, rather than its quality. In this paper we introduce a model for determination of possible locations and amounts of available time reserves. The model assumes that timetable could be represented as network project and, in that way, suitable for the application of methods for the network model analysis. For the analysis, Critical Path Method was applied on small segment of cyclic timetable.*

Keywords – railway timetable, robustness, stability, critical path method.

1. INTRODUCTION

In conditions of heavily utilized railway infrastructure, the quality of timetable becomes more and more important. During the construction phase, the main goal of decision maker is to provide timetable feasibility, assuming that the timetable will be realized in ideal conditions, without any disturbances in traffic management process.

Since by its nature is not of numeric type, the quality of timetable usually is assessed through several established indicators. The robustness of timetable represents the ability of the timetable to withstand small disturbances. The timetable stability is defined as an ability of the timetable to independently return into designed state, after the occurrence of the disturbances [1].

Although robustness and stability both depend on the amount of implemented time reserves, those two indicators should be clearly distinguished, since robustness largely depends on the location of time reserves, and reserves remaining at the end of the cycle have no practical value for the timetable robustness.

This paper describes a theoretical approach to determination of those headways and running times where it would be possible to implement time reserves and thus increase the quality of given timetable. The model should be applied iteratively, but it is not computationally demanding, which guarantees the possibility real world application.

2. ASSUMPTIONS AND MODEL DESCRIPTION

The Critical Path Method (CPM) can be used to unambiguously determine the time duration required to complete a network project if the duration of each activity is known with certainty. For this reason, timetable should be represented as a network project, where the activities are represented by arcs. Activities of interest are train running times, headway times and crossing times in stations. Events, such arrival and departure of the trains are represented by nodes. Hence, each arrival represents the completion of one running time and one headway/crossing time, while each departure represents the end of one headway/crossing time. Passing without stop are special cases: if such event is dependent on some other event, it should be represented by node with indegree of 2 and outdegree of 1; in other cases, if an event is independent on other events, node should be omitted.

Model should be applied throughout several steps. In first step, since CPM requires strictly defined starting and finishing point, "dummy" activity has to be inserted, in a such way that the duration between starting node and first event planned by timetable has time length of zero minutes, as well as the activity between last planned event and finishing node. Second step is timetable compression, in a way that it was suggested in [2].

In this way, the earliest occurrence time of event i (E_i) and event j (E_j), and the latest allowable occurrence

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time of event i (L_i) and j (L_j) are determined, since the planned time of occurrence for event i represents the L_i, while the E_i is determined by the occurrence time of the event i in compressed timetable. For any arc between nodes (events) i and j, marked as activity *(i, j)*, the slack time, *ST(i, j)*, represents the amount of time by which the starting time of given activity could be delayed, without delaying the complete project:

$$ST(i,j) = L_j - E_i - t_{ij} \qquad (1)$$

where t_{ij} represents the duration of activity *(i, j)*. An activity without positive ST is a so-called critical activity.

In the next step, the critical path on the compressed timetable has to be found. A critical path is such a path that consist entirely of critical activities [3]. In our model, in a sequence from starting to finishing node, on critical path all activities representing headways and crossing times will have minimum required values, without any buffer times[1]. Although the critical path could be determined by linear programming model, in this case this is unnecessary. Theoretically, more than one critical path can exist, but this does not affect the application of the model in any way.

With the critical path determined, the total amount of available time reserves is also determined as the difference of the occurrence time of the last planned event and the end time of the entire cycle, minus minimum headway time amount between the last planned event in current cycle and the first planned event in the next one. The total amount of available time reserves applies on activities on the critical path only.

In the fourth step, the buffer times are implemented in headways/crossing times on critical path. If the planned occurrence time of the last event in a cycle is changeable, then that event could be moved at the very end of the cycle, with respect to the headway time for the next cycle.

After the expanding of the critical path, all the events outside that path remain with available time reserves and they could be moved until some of them do not consume all ST between themselves and corresponding event at critical path. The amount of available time reserve for activity *(i, j)*, or free slack time (FST) is defined as:

$$FST(i,j) = E_j - E_i - t_{ij} \qquad (2)$$

If for the buffer times implementation decisions are made in relation to events only, and if the planned occurrence time for event i cannot be delayed, then the available amount of buffer time (slack) is equal to:

$$S(i) = L_i - E_i \qquad (3)$$

When it is not possible to protect all events with a time reserve, the decision maker must select events by his own priorities. The described model does not offer the possibility of optimization location selection nor amount of buffer time used for timetable robustness increasement, so one of developed optimization models, such as [4], could be used.

3. CASE STUDY

The model was tested at small sample of cyclic timetable, presented in Fig. 1.

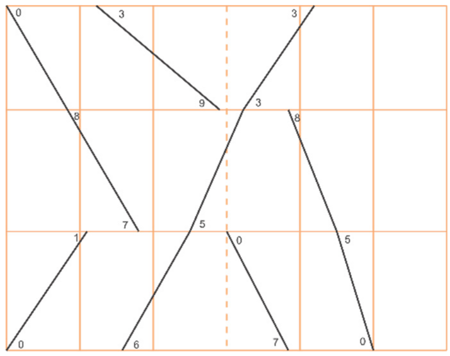

Fig. 1. Timetable segment

The compression of the time table was conducted following the recommendation of the UIC, given in [2]. Compressed timetable is shown in Fig. 2.

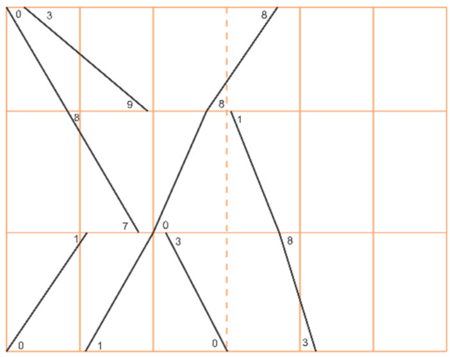

Fig. 2. Compressed timetable segment

After the compression, events and activities relevant to the model were declared. As events, all arrivals and departures were declared as nodes, while for passing through stations events, as nodes were declared only those events that interact with some another event were declared as nodes.

All headway and crossing times were declared as arcs.

As was already said, train running times may contain time reserves as well, but for the simplification of the model that was neglected. In cases where one want to influence timetable robustness and stability, those activities should be divided into two parts – minimum running time and increment time, by insertion of a "dummy" activity between them. Timetable in the form of network project is shown in

[1] *Running times could also be protected by a time reserve, but for simplification it will not be assumed.*

Fig. 3.

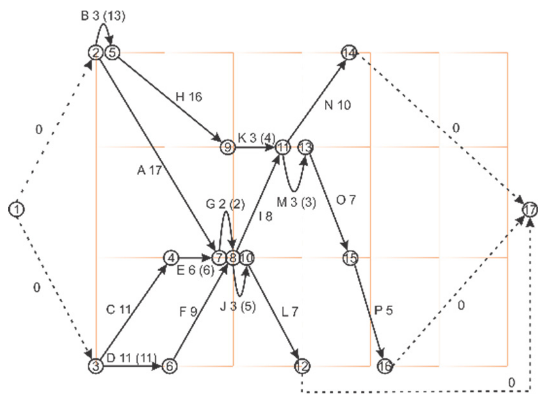

Fig. 3. Nodes and their interdependace in selected timetable segment

Within the network graph, nodes are marked with numbers, while activities are represented with activity duration and letter. Node 1 has two "dummy" activities, while node 17, as a finishing node in the network, has three "dummy" activities. For the activities representing headways or crossing times planned duration is given in brackets, after minimum duration regarding compressed timetable and activity corresponding letter mark. As activities representing running times are unchangeable, only planned duration is shown. All activities and their total slacks are shown in Tab. 1.

Tab. 1. Activities and total floats

Activity	Description	Successors	Predecessor	ST
A	Running	G	-	0
B	Headway	H	-	6
C	Running	E	-	0
D	Headway	F	-	0
E	Headway	G	C	0
F	Running	I,J	D	0
G	Headway	I,J	A,E	0
H	Running	K	B	6
I	Running	M,N	F,G	0
J	Headway	L	F,G	7
K	Headway	M,N	H	6
L	Running	-	J	7
M	Headway	O	I,K	0
N	Running	-	I,K	0
O	Running	P	M	0
P	Running	-	O	0

Now it is possible to determine the critical path of the timetable, and it is shown in Fig. 4.

Since it is necessary to provide the minimum headway time between the last activity within given cycle and the first one within the following one, the sum of available time reserves for activities on critical path is 14 minutes.

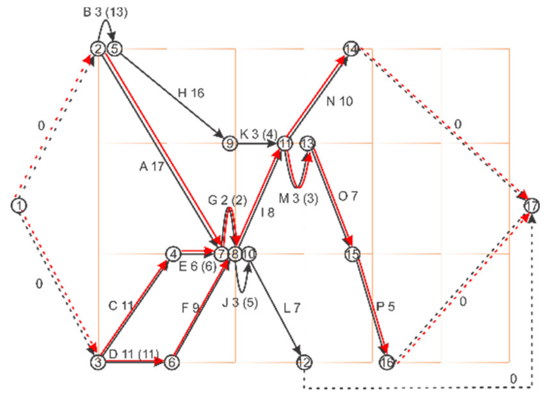

Fig. 4. Activities on critical path

It is obvious that only activities D, E, G and M could be extended since all other activities on critical path represent running times. However, activity E has so-called "strong connection" since neither starting time of activity A or C cannot be postponed. Further, since the activity F represents the running time, activities D and G are "strictly dependent" on each other, which practically means that only activities G and M could be extended. For the purpose of this paper, both activities were extended for 5 minutes, which enabled 4 minutes time reserve for the headway time between cycles. Timetable with extended critical path is shown in Fig. 5.

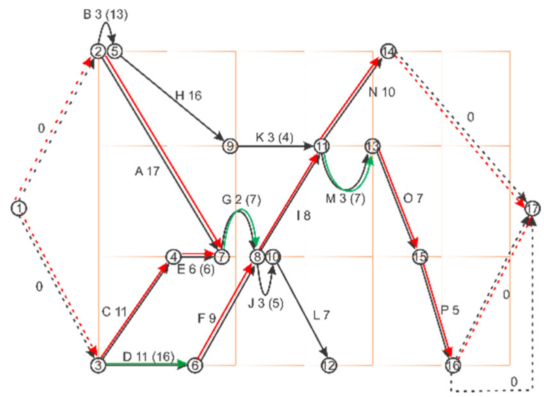

Fig. 5. Timetable graph with extended headways on critical path

Now, activity J remains "unprotected", but free as long as its moving to the right on the time axis does not threatens the headway between nodes 10 and 15. Further, start of activity H can be set anywhere between 3rd and 13th minute, but beginning of that time interval does not provide any buffer time to headway between nodes 2 and 5, while the end of the interval disables time reserve for the crossing time between nodes 9 and 11.

In this case study start of activities H, K and L was postponed for 5 minutes, i.e., duration of activity K was shortened for the same amount. The final appearance of timetable is given in Fig. 6.

In order to compare original and improved timetable, a series of simulations was performed. For the purpose of comparation, same random initial delays were generated for original and improved timetable, both. Generated delays could take the value between 3 and 7 minutes and they could occur in the duration of headways or crossing times only. Comparation was done regarding the generated secondary delays by calculation average delay per event (node), *ADE*, and average delay per one minute of initial delay, *ADI*.

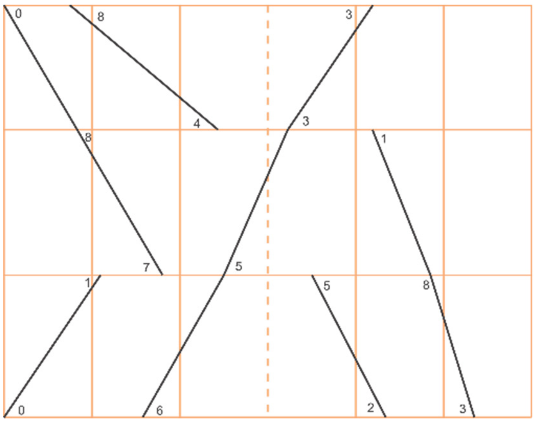

Fig. 6. Improved timetable

Since this was a small example, the use of complex simulation software was unnecessary, so we decide to perform the simulation using the max-plus algebraic model defined in [5]. Simulation results are given in Tab. 2.

Tab. 2. Simulation results

Timetable	ADE	ADI
original	4.81	5.01
improved	4.12	4.99

Improved timetable generated smaller secondary delays for 3.99%. Since the model was tested on small timetable example only, even better results can be expected on a larger sample.

4. CONCLUSION

The described model provides a simple method for analysis and suggestions for improvement timetable quality by increasement of its robustness. The developed model uses the network project analysis tool, critical path method. The model is not complex nor computationally demanding but requires a strict sequence of steps. It does not provide an optimal solution but guarantees that obtained solution cannot be less robust than initial one.

Although the developed model neglects the potential time reserves in train running times, a very simple extension of the model makes possible for those times to be considered.

The level of details can be additionally adjusted through the selection of only those events whose realization time is declared as "changeable".

Since the delays are, by their nature, random events, further improvement of the model should incorporate the probability of their occurrence. Also, as in commercial timetables rank of the trains is usually different, the priority of protection also differs, which should be built in model.

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XX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
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DEFINITION OF THE OPERATIONAL REQUIREMENTS FOR AN OBSTACLE DETECTION SYSTEM USING RISK-BASED APPROACH

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Abstract *– Automation of railway traffic has been a generally accepted trend in recent years and represents one of the main conditions for the further development of this type of transport. Automatic control of trains/traction units implies the introduction of an obstacle detection system. The usual approach to defining operational requirements for the development of new technical systems on railways is the so-called project approach, where operational requirements for a new system are defined in advance, according to valid standards, defined goals and available technology. However, the development of obstacle detection systems has its own specificities, where this approach does not necessarily give satisfactory results. Successful functioning of this system in terms of railway traffic safety, i.e., successful detection of obstacles is not a goal in itself, the goal is avoiding the obstacle or minimizing its negative impact as much as possible. In order to achieve this, in addition to successfully detecting an obstacle, it is necessary to react adequately to it. Therefore, for defining the operational requirements for such system, it is necessary to start from the analysis of the requirements in terms of adequate response and not from the requirements in terms of obstacle detection. This implies the application of a risk-based approach.*

Keywords – Railway traffic, Automatization, Obstacle detection, Operational requirements, Risk.

1. INTRODUCTION

For the successful development of the railway system in relation to other modes of transport and increasingly demanding conditions on the transport market, its automation is necessary. This process is ongoing in all segments of the railway system, especially in the areas of traffic management and maintenance of transport and infrastructure capacities.

Tab. 1. Main characteristics of the five Grades of Automation (GoA)

GoA levels	Door Closure	Setting train in motion	Stopping train	Operation in case of disruption
GoA0	Driver	Driver	Driver	Driver
GoA1	Driver/Automatic	Driver	Driver	Driver
GoA2	Driver	Automatic	Automatic	Driver
GoA3	Attendant	Automatic	Automatic	Attendant
GoA4	Automatic	Automatic	Automatic	Automatic

Automation, after electrification and the introduction of high-speed trains, represents the third revolution in the development of railway transport. In the field of railway traffic, there are four levels of automation (Table 1.) [1].

In the case that remote control and management of the vehicle from the command/dispatch center is possible, the level of automation is additionally marked with a + sign.

Full automation implies GoA level 4, in which case the traction unit is controlled without the presence of a person in the cabin. One of the most important systems for the complete automation of railway traffic is the system for detecting obstacles on the driving path. Regardless of the fact that the train path is controlled and that as a rule there should not be any obstacles on it, the effectiveness of that control is not such to provide the real absence of all risks associated with obstacles on the train path.

So far, GoA 4 level of automation has been implemented in several metro and light rail systems. The only application in classic railway systems is on the Rio Tinto mining tracks in Western Australia, where fully autonomous operations for its entire rail system has been in use since 2019. This Rio Tinto's rail network is recognized as the world's first fully

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autonomous rail network [2].

All systems in which GoA 4 level of automation has been implemented so far are significantly different from most public railways system in terms of the type and magnitude of risks associated with obstacles. They are either closed systems such as subways, mining lines in desert areas without major environmental hazards, or light rail systems with low speeds and short stopping distances. Experiences from these systems are only applicable to a limited extent for the classic public railways.

The introduction of GoA 4 level of automation in public railway traffic is planned worldwide. EU countries and Russia have gone the furthest in this process, where test drives and tests of obstacle detection devices are carried out. In the US and China, the introduction of this level of automation is still in the planning phase [2, 3, 4].

The development and implementation of any new railway system requires the definition of functional and operational requirements for it. The usual approach to defining operational requirements for the development of new technical systems on railways is the so-called project approach, where operational requirements for a new system are defined in advance, according to valid standards, defined goals and available technology. However, the development of obstacle detection systems has its own specificities, where this approach does not necessarily give satisfactory results. In order to achieve this, in addition to successfully detecting an obstacle, it is necessary to react adequately to it (warning, reducing speed, braking). Therefore, in terms of defining the operational requirements for such a system, it is necessary to start from the analysis of the requirements in terms of adequate response and not from the requirements in terms of obstacle detection. This implies the application of a risk-based approach, that is considered in this paper.

2. DEFINING THE OPERATIONAL REQUIREMENTS FOR THE OBSTACLE DETECTION SYSTEM

The traditional approach to defining the operational requirements for a new technical system on the railway is to define them in advance based on the project goals. For the obstacle detection system, they mainly refer to the definition of object/obstacle categories that the system should detect and the maximum distance of their detection.

2.1 Project base defined operational requirements for the obstacle detection system

In most projects currently implemented in the EU, the operational requirements include the detection of the following object categories [3] (table 2.):

Tab. 2. Objects that represent an obstacle to the safe movement of the train

1. Objects within the railway system	**Obstacle detection distance**
1.1. signals prohibiting further driving	brakingdistance
1.2. broken signals	braking distance
1.3. the position of the switch blades	it is not precisely defined - only when the train stops and starts
1.4. other railway vehicles in the path	it is not precisely defined - only on shunting
2. Other objects	**Obstacle detection distance**
2.1 objects in the free (Bern) profile	≈ 2000 m
2.2. people in the free (Bern) profile	≈ 2000 m
2.3. animals in free (Bern) profile	≈ 2000 m
2.4. road vehicles in free (Bern)profile	≈ 2000 m

The disadvantage of the operational requirements for an obstacle detection system defined in this way is that it does not take into account the magnitude of the risk associated with different categories of obstacles and the way the control system reacts depends on the size of that risk.

Operational requirements defined in this way can function satisfactorily in conditions where for each category of obstacle there is only one usual way of reacting: quick braking with possible warning signs, as is the case with trams. However, this is not the case in railway traffic.

Fast braking ie. emergency braking also represents a risk to traffic safety, sometimes greater than the risk represented by the obstacle itself, and should not be applied by default.

Also, the risk carried by a certain category of obstacles depends on other factors: position, dimensions, speed and direction of movement, etc. and their identification is also required for the correct selection of regaging.

Operational requirements defined in this way increase occurrence of false positives (where ODS detects obstacles that do not present real collision risk). This can be a problem for the application of GoA level 4 in tram LRT systems [5], and in the railway system it would certainly have very large negative consequences on the regularity of traffic and the economy of the system.

Last but not list, the operational conditions defined in this way for the obstacle detection system take usual into account only obstacles in the free profile (so called Bern profile). However, considering the length of braking distance in railway traffic, it is necessary to observe a wider strip next to the tracks where there may be objects that could endanger the safety of traffic. Reaction (warning, reduction of speed, etc.) to such objects must take place (existing railway regulations also require it) before they enter in the free profile.

Bearing in mind the definitions of risk on the railway (Risk is the probability of the occurrence of a dangerous event multiplied by the magnitude of possible consequences) and the frequency of certain dangerous events, it can be concluded that in fact the most important task of the obstacle detection system is to recognize these types of dangers and enable warning about them.

Although warning drivers, pedestrians and animals with sound and light signals is not in the foreground when thinking about obstacle detection, it is very important. Research conducted in the late 80s in the USA by the FRA (USA Railway Safety Authority) in connection with the ban on giving audible (whistle) signals at level crossings in urban areas, which the state of Florida tried to introduce, showed that the omission of warnings with audible signals increased the number of fatalities at level crossings by about 38% [6].

Bearing in mind that accidents with collisions with vehicles and people are by far the most numerous dangerous events on European railways (10 times more numerous than the number of significant accidents resulting from train collisions with obstacles) and that for every collision of a train with road vehicles or people there are minimum 10 near miss collisions, it is easy to conclude that from the aspect of overall risk, the most important task of the obstacle detection system is to recognize moving objects in the area next to the free profile [7].

2.2 Risk-based approach

Real risks on public railways cause more complex operational requirements for the obstacle detection system than just recognizing the category of an object at a certain distance. Obstacle detection system would have to be able to detect ie. recognize not only the type of obstacle, but also the level of risk.

More detailed operational requirements for the obstacle detection system were defined by Russian Railways (RDŽ) [4]. Their classification of obstacles that should be recognized by obstacle detection system is more detailed and includes moving objects in the belt next to the tracks (table 3). In addition, it defines the basic type of risk related to an individual category of obstacles.

Until now, RDŽ has performed tests in the so-called GoA 3+ level, which means that the train was controlled remotely from the command center. In that case, this level of risk determination is sufficient because after the detection of an obstacle by the system, the dispatcher takes over the control of the train, i.e. defines the way of reacting to an obstacle.

Tab. 3. RDŽ classification of obstacles for obstacle detection system [4]

№	Class	Subclass	Status or description	Threat to an obstacle	Threat to a vehicle
1	Pedestrians	Adults	Standing, moving, sitting, lying	Yes	No
		Kids	Standing, moving, sitting, lying		
2	Animals	Big animals (examples: cow, horse, moose)	Standing, moving, sitting, lying	Yes	Partially (at high speed)
		Medium and small animals (examples: goat, dog, cat)	Standing, moving, sitting, lying	Yes	No
3	Train units	Locomotives, train cars, maintenance vehicles and etc.	Standing, moving	Yes	Yes
4	Road vehicles	Cars, trucks	Standing, moving	Yes	Yes
		Motorcycles, bicycles		Yes	No
5	Static obstacles	Big (cross section area in the plane perpendicular to the rails is more than 0.5 m^2)	Violation of the clearance gauge : building construction, fallen tree, tilted posts and other constructions	No	Yes
		Medium (cross section area in the plane perpendicular to the rails from 0.1 to 0,5 m^2)	Boxes, shrubs, parts of building constructions	No	Partially
		Small (cross section area less than 0,1 m^2)	Brake shoe	No	Yes
			Stones, rail tools and mechanisms	No	Partially
			Various items (boxes, wood boards and etc.)	No	No
6	The defects of infrastructure	Sun kink, a drawdown of the track, broken rails		No	Yes
		breakage, sagging of catenary		No	Yes
7	Natural phenomenon	Flooding of tracks, undermining of tracks		No	Yes
		Fire		No	Yes
		Snowdrift		No	Partially
		Landslide, mudflow		No	Yes

For a fully automatic train control system of level GoA 4, the risks related to the obstacles defined in this way may not be sufficient. Therefore, within the SMART 2 project, more detailed operational requirements for the obstacle detection system were defined [8]. The two most related to the recognition of all the necessary characteristics of the object that represent obstacles and the determination of the levels of risks associated with them are:

OR-RAM-04 The OD&TID system shall provide the necessary data for train control/TMS systems to make proper control decision to avoid collisions with object/obstacles or restrict severity of collisions to the extent that the operational risk is assess as acceptable.

OR-SS-02 The system algorithm shall calculate the hazard rate associated with a detected object and communicate the hazard rate and detection information to other systems.

The operational requirements for the obstacle detection system defined in this way allow that with the GoA 4 level of automation, all risks associated with obstacles in the train path train can be successfully controlled.

3. CONCLUSION

The complete automation of railway traffic at the GoA4 level implies that many control functions previously carried out by man/engine driver will be taken over by technical train control and management systems. To adequately define operational requirements for such systems, it is better to apply the so-called risk-based approach rather than the usual project-based approach. This is especially valid for the obstacle detection system because the correct way of reacting to the appearance of an obstacle depends not only on the type of obstacle but also on the risk related to it in every specific case. In addition, the risk-based approach also enables the assessment of requirements in terms of preventive action, i.e., potential obstacles, which is not the case in the so-called project approach.

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APPLICATION OF OPENTRACK AT SALZBURG AG

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Abstract *– This paper describes how software OpenTrack has been applied for the design of new railway infrastructure in Austria at Salzburg AG. The local railway company already operates a network of 38 km which consists out of one line from Salzburg Lokalbahn to Lamprechtshausen over Bürmoos where there is a junction to Ostermiething. Passenger trains operate in a 30 minutes interval while express trains are additionally running in peak time period. Software OpenTrack allows railway engineers to simulate railway operation on different infrastructure layouts. Typically, there is a demand for a certain type of railway services (e.g. an integrated timetable). To enable these services several scenarios of topology can be developed. By simulating railway operation on these scenarios the stability of the timetable can be evaluated. Extensions of existing topology can be justified by running such a simulation. Additionally, upgrades of signalling system can be analyzed in detail which is also applied at Salzburg AG.*

Keywords – Planning, Topology, Infrastructure, Signalling, Simulation.

1. INTRODUCTION

OpenTrack was developed at the Swiss Federal Institute of Technology's Institute for Transportation Planning and Systems (ETH IVT). The project's goal was development of a user-friendly railroad simulation program that can run on different computer platforms and can answer many different questions about railway operations [1].

Figure 1 illustrates the three main elements of OpenTrack: data input, simulation, and output.

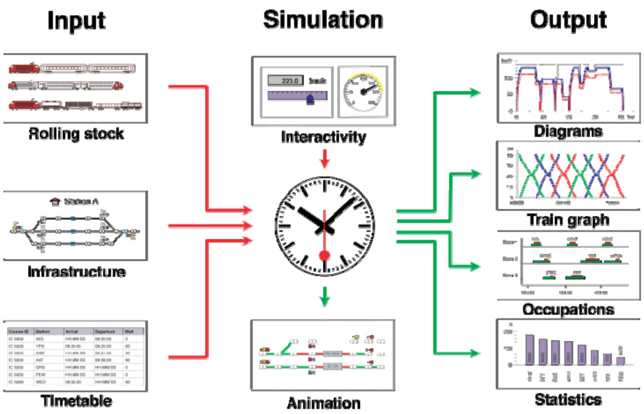

Fig.1. Data flow in OpenTrack

OpenTrack is a microscopic synchronous railroad simulation model. As such it simulates the behaviour of all railway elements (infrastructure network, rolling stock, and timetable) as well as all the processes between them. It can be easily used for many different types of projects including testing the stability of a new timetable, evaluating the benefits of different long-term infrastructure improvement programs, and analyzing the impacts of different rolling stock.

Since 2021 software OpenTrack is also successfully used by Salzburg AG in Austria. First task was to model the existing infrastructure in OpenTrack. Afterwards, an implementation of the European Train Control System could be simulated to evaluate the impact on the timetable. Finally, an extension of infrastructure to allow a 15 minutes interval cross the entire day has been simulated.

2. ABOUT OPENTRACK

OpenTrack administers input data in three modules: rolling stock (trains), infrastructure, and timetable. Users enter input information into these modules and OpenTrack stores it in a database structure. Once data has been entered into the program, it can be used in many different simulation projects. For example, once a certain locomotive type has been entered into the database, that locomotive can be used in any simulation performed with OpenTrack. Similarly, different segments of the infrastructure network can be entered separately into the database and then used individually to model operations on the particular segment or together to model larger networks.

Train data (locomotive and wagons) is entered into

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the OpenTrack database with easy to use forms displayed using pull down menus. Infrastructure data (e.g. track layout, signal type/location) is entered with a user-friendly graphical interface; quantitative infrastructure data (e.g. elevation) is added using input forms linked to the graphical elements. Following completion of the RailML data structure for rolling stock and infrastructure, OpenTrack will be modified to enable train and infrastructure data to be directly imported from RailML data files [2].

Timetable data is entered into the OpenTrack database using forms. These forms include shortcuts that enable data input to be completed efficiently. For example, users can designate hourly trains that follow the same station stopping pattern an hour later. Since OpenTrack uses the RailML structure for timetable data, timetable data can also be entered directly from various different program output files as well as database files.

In order to run a simulation using OpenTrack the user specifies the trains, infrastructure and timetable to be modeled along with a series of simulation parameters (e.g. animation formats) on a preferences window. During the simulation, OpenTrack attempts to meet the user-defined timetable on the specified infrastructure network based on the train characteristics. OpenTrack uses a mixed continuous/discrete simulation process that allows a time driven running of all the continuous and discrete processes (of both the vehicles and the safety systems) under the conditions of the integrated dispatching rules.

The continuous simulation is dynamic calculation of train movements based on Newton's motion formulas. For each time step, the maximum force between the locomotive's wheels and the tracks is calculated and then used to calculate acceleration. Next, the acceleration function is integrated to provide the train's speed function and is integrated a second time to provide the train's position function.

The discrete simulation process models operation of the safety systems; in other words, train movements are governed by the track network's signals. Therefore, parameters including occupied track sections, signal switching times, and restrictive signal states all influence the train performance. OpenTrack supports traditional multi-aspect signalling systems as well as new moving block train control systems (e.g. European Train Control System – ETCS signalling [3]).

Finally, dynamic simulation enables users to run OpenTrack in a step-by-step process and monitor results at each step. Users can also specify exactly what results are displayed on the screen. Running OpenTrack in a step-by-step mode with real time data presented on screen helps users to identify problems and develop alternative solutions.

One of the major benefits of using an object oriented language is the great variety of data types, presentation formats, and specifications that are available to the user. During the OpenTrack simulation each train feeds a virtual tachograph (output database), which stores data such as acceleration, speed, and distance covered. Storing the data in this way allows users to perform various different evaluations after the simulation has been completed.

OpenTrack allows users to present output data in many different formats including various forms of graphs (e.g. time-space diagrams), tables, and images. Similarly, users can choose to model the entire network or selected parts, depending on their needs. Output can be used either to document a particular simulation scenario or as an interim product designed to help users identify input modifications for another model run.

3. APPLICATION AT SALZBURG AG

The local railway company operates a network of 38 km which consists out of one line from Salzburg Lokalbahn to Lamprechtshausen over Bürmoos where there is a junction to Ostermiething. Passenger trains already operate in a 30 minutes interval while express trains are additionally running in peak time period. Existing infrastructure has been successfully modelled in OpenTrack (see figure 2). This was the starting point for further research when implementing the European Train Control System Level 2.

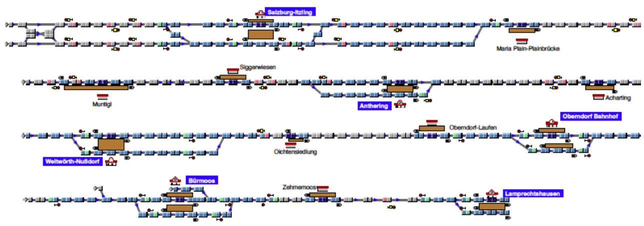

Fig.2. Part of infrastructure network

Starting with the existing railway infrastructure topology ongoing extensions close to Bürmoos were added to the model. A short double track section reduces delays due to a train crossing. The benefit of this investment could be clarified. Afterwards, the entire infrastructure was equipped with GSM-R functionality. This allows trains to run by cab signaling instead of wayside signals. Related to this implementation are two parameters to describe the operational performance: release speed and deceleration delay. Both parameters have been set in accordance to standards used by Austrian Railways ÖBB in other ETCS projects [4]. For the evaluation of the operational performance the delays with or without ETCS at the last stop of each course have been evaluated. Delays are grouped by the four final destinations of all courses in the timetable.

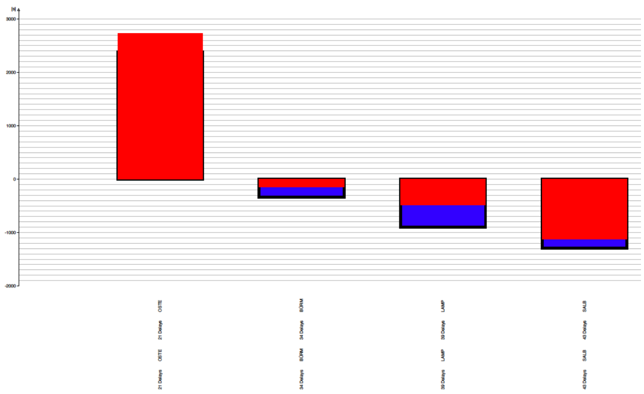

Fig.3. Delays with or without ETCS

Blue color is used for delays without ETCS while red color to indicate delays with ETCS. The delays are grouped for the four terminal destinations Ostermiething, Bürmoos, Lamprechtshausen and Salzburg. Delays are displayed in seconds. For all terminal stations the trend is the same. While delays increase for station Ostermiething earliness for all other stations decreases (figure 3). This can be explained by the parameters of the more restrictive ETCS braking curves.To justify investments in the near future, the punctuality of a 15 minutes interval service (figure4) has been also simulated. The new timetable concept offers only one type of courses which stops in all stations. Therefore, the existing fast trains are cancelled. Every 30 minutes one course goes to Lamprechtshausen while every other 30 minutes a course goes to Ostermiething. This results in a 15 minutes interval on the common used section between Salzburg and Bürmoos.

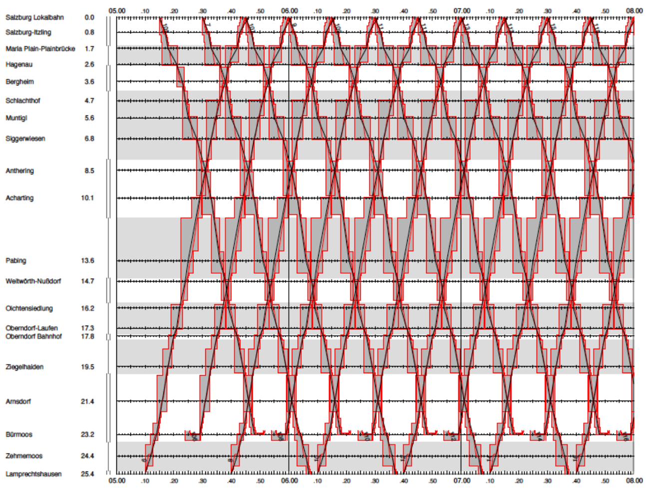

Fig.4. New Timetable Concept

To justify investments in the near future, the punctuality of a 15 minutes interval service (figure4) has been also simulated. The new timetable concept offers only one type of courses which stops in all stations. Therefore, the existing fast trains are cancelled. Every 30 minutes one course goes to Lamprechtshausen while every other 30 minutes a course goes to Ostermiething. This results in a 15 minutes interval on the common used section between Salzburg and Bürmoos.

Furthermore, new vehicles will be used to replace the old generation from the 70ths which do not allow a barrier free boarding of passengers. Of course, the tractive effort diagram of this new vehicle was added to the OpenTrack model. Further information about the new vehicle can be found on the homepage of company STADLER [5] which is well known in Serbia.

4. CONCLUSION

The application of software OpenTrack has been a useful tool to evaluate the investments in railway infrastructure to enable a 15 minutes interval on the highly frequented local railway lines of Salzburg AG. Moreover, the impact of new vehicles on the punctuality of the timetable could be simulated. Additionally, the consequences of an implementation of the European Train Control System on the performance could be demonstrated. Further investigations can be easily carried out with the existing models. Of course, it is necessary to invest some time in the creation of precise models of infrastructure, rolling stock and timetable.

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XX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
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STATISTICAL URBAN TRAFFIC EVALUATION IN THE CITY OF CONSTANTINE: CASE OF THE ZOUAGHI SLIMANE CROSSROADS

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Abstract *– Through this work, we have launched a statistical survey for the collection of data relating to the mode of circulation at the Zouaghi Slimane crossroads. The critical parameters chosen are the waiting time and the level of comfort and safety in the time's function of the day. We observed that the phenomenon of congestion is present at this crossroads. This situation leaves us to ask the following question: how can we reduce the lost time at these crossroads? Moreover, how to solve the congestion problem knowing that we have multimodal traffic and a lot of interaction between modes? In response to this statistical study, which consists in taking stock of traffic at the Zouaghi Slimane crossroads to highlight the mode of transport most used and frequented by the citizens of the city of Constantine added to that, highlight the probable causes of the very constraining congestion state at optimal fluidity.*

Keywords – Multimodality, Survey, crossroads, journey time, congestion, traffic.

1. INTRODUCTION

Constantine is known for being a city established on a rock. It is therefore beyond the old rock that the urban extensions took place in recent decades. They occupied the spaces bordering the city with a turbulent topography and an anarchic urban dynamic that the third city of the country knows. This has led to an ordeal in urban transport daily in the city of Constantine and in particular for the new poles that have benefited from housing and rehousing programs. Thus, the outlying areas of this city are experiencing a strong population growth never imagined since independence [1].

In recent years, the city of Constantine has also experienced a very strong development of public transit [2]. However, individual transport in these different forms has fairly obvious flexibility with public transport and has thus taken an increasingly important part in recent years. This partly explains the vigorous growth in traffic, particularly in urban areas. We also note that mobility in the city of Constantine is affected by bus, car, two wheels, taxis, on foot, etc., or using any combination of these different modes.

The share of public transport in the support of all motorized modes is 58%. This percentage confirms the improvement in the public transit supply network over the past decade. The problems of congestion, pollution (air and noise) and road safety which result from it, encourage the public authorities and the transport companies to multiply the efforts to maintain or even improve the quality of the services offered to the users, to make public transport more attractive. From now on, the quality of life in a city is determined by the efficiency of its arsenal of means of transport and its mobility[9,10]. The latter is becoming increasingly important and has become one pillar of the urban condition, even supporting the transition to more resilient, secure, fair, and sustainable transport and mobility systems [3].

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2. PRESENTATION OF TRAFFIC ROAD AT ZOUAGHI SLIMANE JUNCTION CROSSROADS

Zouaghi Slimane crossroads comprising twelve branches is a case study for its multi-modality and its very important geographical position near the Mohamed Boudiaf airport and the University of Mentouri Constantine ; it is also the crossing of a set of destinations towards the new city Ali Mendjeli, El Khroub, the entrance, and exit of the east-west motor road… etc. It is a mandatory passage between the city of Constantine and the new city of Ali Mendjeli. The latter has become the most important urban crossroads of the agglomeration due to the wealth of its facilities and the importance of its activities [3]. Because of its particularity, the urban transport network at this junction is quite dense and sometimes there is almost no fluidity for long periods, as the black points in shown in Figure 1, which are junctions and sources of congestion in the absence of optimal regulation at this intersection.

Fig.1. Zouaghi Slimane crossroads

According to this situation and from our point of view, a solution would be to develop tools for optimal regulation and management of the traffic. However, before modeling the evolution of the density of road traffic over time and study space, it is very important to have an overall traffic situation at this intersection. For this, we have put in place a questionnaire which is a very adopted quantitative data collection method [5] to analyze the data of the three modes (Tram, Bus, and Private Vehicles or Taxi); whose aim is to study the equity between the modes of transport used at the intersection.

3. RESULTS OF THE STATISTICAL SURVEY

We compiled a questionnaire with a targeted sample of 140 people of all ages and categories. It is established based on two main indicators: a qualitative indicator and a quantitative indicator [6] whose aim is to analyze the data of the three transport modes present at the Carrefour, namely Tramway, Buses, and Private Vehicles or Taxis and measure equity between the three modes.

The first results show that the quick densification of the population has resulted in a remarkable need for mobility, with a rather small interval between the three modes of transport where the share of public transport (T.C.) in the management of travel is around 70%. The measurement of the satisfaction level of uses shows a high degree of satisfaction to the tramway.

Waiting time matters in the choice of the transportation mode. The results of the statistical survey on the measurement of waiting times at bus and tram stations clearly show that waiting at bus stations is much more important than waiting at tram stations. We note that the waiting time for VP (taxi) is very low and has therefore not been considered.

Which concern the measurement of PV (taxi) journey time, results shows that the travel time spent by the VP(Taxi) at the Zouaghi Slimane crossroads is manifested by a bell curve with a maximum peak between 5 and 15 minutes which can reach travel times of over 30 minutes, but on average the wait is about 15 to 30 minutes as shown in figure 2. This clearly shows that congestion is present at these junctions.

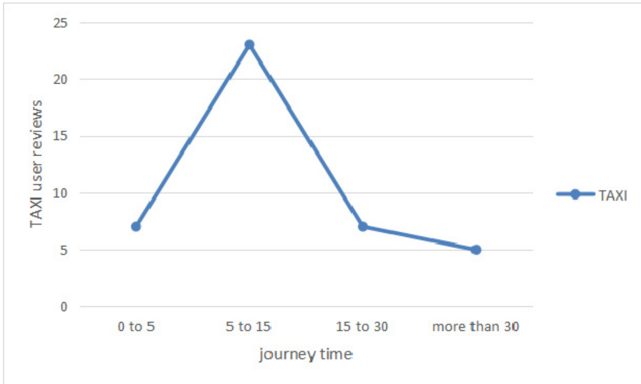

Fig.2. Journey time curve at the Zouaghi crossroad

For well conducted periods of congestion we choose to measure the periodicity of crossing the intersection, the results show that the use of the three modes of transport at a decreasing rate according to the period. The use of the 6am-9am and 9am-4pm buses is greater than that of the passenger car (Taxi) and the tram, this trend is reversed from 4pm-7pm to 7pm-6am in favor of the tram.

The results of the User Satisfaction Survey by Contribution to Travel Time are presented gave 84% negative answers, which reflects the dissatisfaction of most users.

By comparing the result of the journey time satisfaction of the three modes, the statistical survey shows that the tramway is the most satisfactory means of transport concerning the journey time at the Zouaghi crossroads. Then appears the VP (Taxi) and the buses at the end. This justifies that 60% of responses mention the tram as the most preferred mode (See Figure 4).

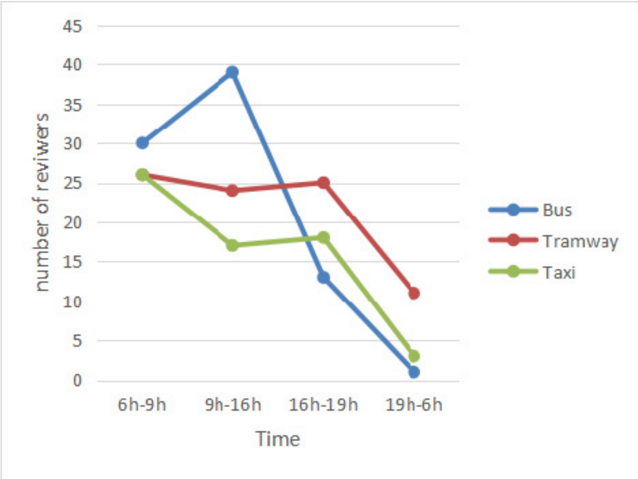

Fig.3. Frequency curve based on user feedback

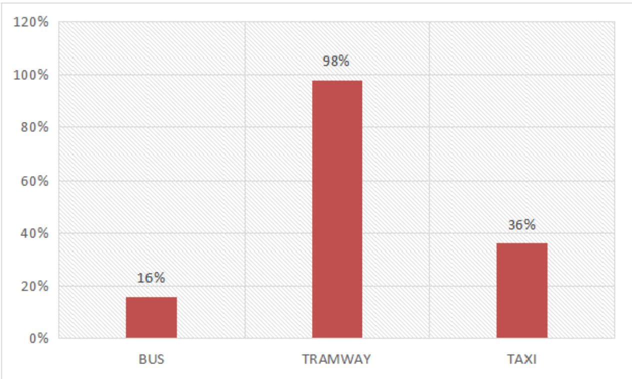

Fig.4. Ridership satisfaction: travel time between the three modes

Related to the study by preferred mode of use. We wanted to have the reasons of the choice of this or that mode of transport the results shows that on the trend of comfort and travel time, the buses are out of classification; the users prefer the use of the tram in the first place, then comes taxis (VP) for the aspect of timesaving, price, comfort, and safety as shown in figure 5.

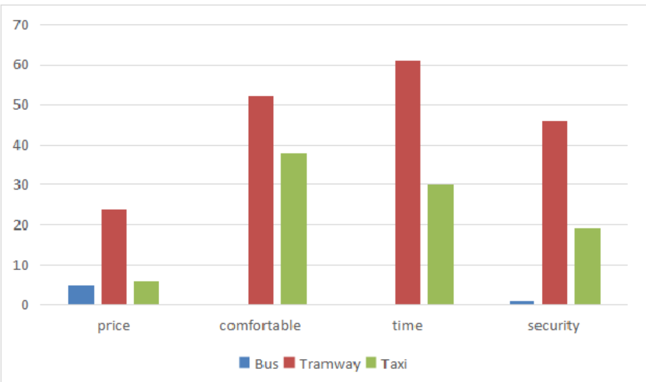

Fig.5. Histogram of the trend of users between the different modes.

The causes of displacement by the Zouaghi Slimane crossroads have been also highlighted by the measurement of the pretexts of crossing at these crossroads of uses. The results shows that the causes of crossing at the crossing are mainly working, then for education and in third position leisure and the end travel to the administration.

And finally we want to know the assessment of the multi-modality at this Carrefour, according to Figure 2, we observe that the multi-modality is present between the three bus-tram-VP modes in first position or VP-tram or tram-bus, then later the users who use only one mode. The calculation of the percentages shows the predominance of the Bus-Tram-VP mode at this intersection.

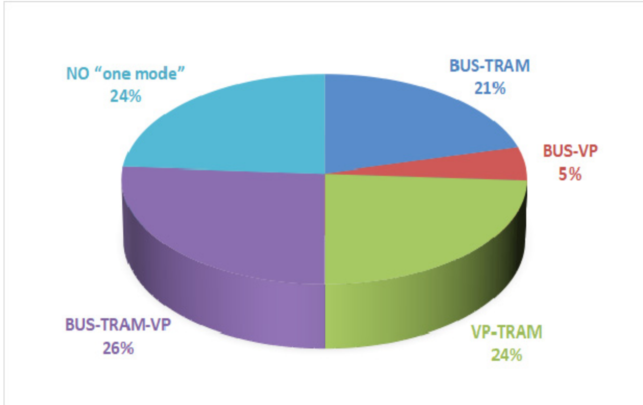

Fig.6. Observation of the multi-modality.

4. CONCLUSION

In conclusion, we can confirm that a good urban transportation network is more than essential to the proper functioning of a city that respects itself. Wasting time waiting for transportation or arriving late at its point of fall makes society less productive and inevitably results in considerable economic loss and a contribution to the social and cultural health of the negative inhabitants. From now on, the quality of life in a city is determined by the efficiency of its arsenal of means of transport and its mobility. The phenomenon of congestion is present at this crossroads. According to the results got, the elapsed journey time at the Zouaghi Slimane crossroads can reach over 30 minutes; but on average, the wait is of the order of 15 to 30 minutes. This situation leaves us to ask the following question: how can we reduce the time lost at these crossroads? And how to solve the congestion problem knowing that we have multimodal traffic and a lot of interaction between modes?

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TELEMATICS FOR RAIL FREIGHT – CHALLENGE OF BRINGING TOGETHER NON-EU AND EU RAIL FREIGHT INFORMATION SYSTEMS

Mickael VARGA[1]

Abstract *– This paper and linked presentation will concentrate essentially on the content and story of the EU regulation about Telematics for Rail Freight transport. In this context we will present the story and the state of the art of this regulation and its technical challenges to enable standardized data exchange (such as train running, train preparation, estimated time of arrival etc.) between railways, infrastructure managers and combined transport operators with the European Union. This paper and presentation will on the other hand also give insights about the detailed technical issues which might arise on the borders between the EU and its neighbors. Of course, we will give here hints about what might be the potential technical/legal solutions which we study right now enabling the smooth operation of trains and goods on the borders.This paper and presentation will give detailed data interoperability analysis results and some lessons learnt during the implementation of this regulation about Telematics for Rail Freight transport.*

Keywords – telematics, rail freight transport, combined transport, interoperability, TAF TSI regulation.

1. RAIL FREIGHT TELEMATICS IN THE EU-CONTEXT

Since several decades it is the intention of European Union to create the Single European Railway Area [1]. The goal of this is the developments of an efficient and competitive EU-wide railway network which aims to

1. open the railway market to competition
2. increase the *interoperability* of national railway systems
3. define the framework for a single European railway area.

This paper concentrates on the second item where the focus is on the achievement of rail freight interoperability from telematics point of view. To increase the rail interoperability, the European Union has introduced the as primary legislation the Rail Interoperability Directive [2] which breaks down the European rail network into several so-called sub-systems such as rail infrastructure, rolling stock, energy, locomotives, etc for which the Technical Specifications for Interoperability (TSIs) describe each of the sub-systems.

The most interesting sub-system for this paper is the subsystem for rail freight telematics. This rail freight telematics sub-system is described in the Telematics Applications for Freight - Technical Specifications for Interoperability (TAF TSI), which is a secondary legislation in the EU [3].

The aim of this TAF TSI regulation is to ensure that railways, rail infrastructure managers and combined transport actors can exchange standardized and interoperable electronic messages in order to ease the communication, among others, for the functions of train operation, train positioning, wagon tracking, consginment and the estimation of train / wagon arrival times at their destination (customers sidings, harbours combined terminal) at European level including also Norway and Switzerland.

Please note that above messages are event based, which means that they will be sent from the sender to the recipient only if a condition is fulfilled (such as train is ready for departure) or an event triggers it (such as passing through a train movement reporting point).

2. TAF TSI – THE TECHNICAL IMPLEMENTATION

Even though the TSI is in force since several years, the implementation of above functions needed over the year a closer supervision from the EU institutions and in particular from the European Union Agency for Railways (ERA) [4].

ERA was entrusted by the European Commission with the monitoring of the TAF TSI functions and hereby had to investigate several questions.

The data exchange in this TSI is based on XML [5] messages with a linked data catalogue for message validation. This catalogue (together with description of the use case for the exchange of the messages) is integral part of the legislation, as a technical annex [6]. The XML messages are described in the TSI as follows:

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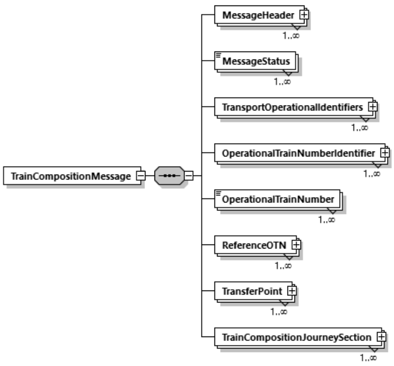


Fig.1. Example of TAF TSI Train Composition message in the data catalogue.

This means that the exchanged messages have to respect he same structure and data content as stated above.

As the reader can imagine, the implementation of such messages at European scale was facing some challenges as some of the bigger railways or rail infrastrucure manager were either in the middle of the lifecycle of their IT systems or had different production processes not entirely corresponding to above use cases. In addition, the harbours and combined terminals – assuring the first and last miles in the transport chain – did not have any standarised mesage structure and IT systems.

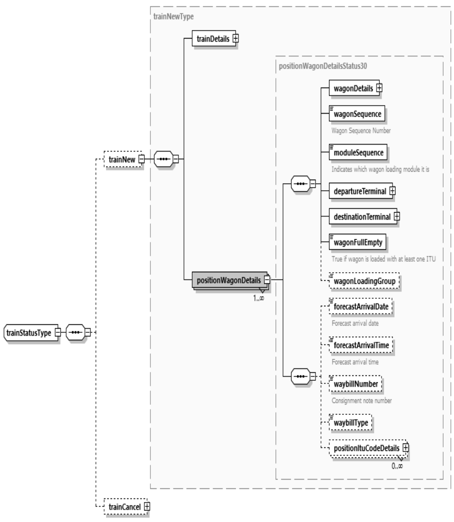


Fig.2. Example of EDIGES [7] Train Composition message used by combined transport actors

Following Train Composition message used by the European combined transport actors (Fig. 2.) makes it visible for the reader that it is different compared to the TAF TSI message from Fig. 1.

On top of above issue, the EU member states, using such messages, have to ensure that trains and consignments coming from or going to non-EU member states can be well monitored as to avoid long inspection and waiting times at such borders. This problem became more and more imminant with borders to Serbia, Ukraine, Bielorussia and Russia where the freight flows were sinificant and where the railways had their own proprietary IT systems and messages since decades.

This situation triggered the need at the EU to ask ERA to investigate how above XML based TAF TSI messages can be translated into a format which would be a meaningful communication layer for railways within the EU and from the neighbouring non-EU countries.

In order to adress this topic, the TAF TSI has introduced (based on ERA recommendation to the European Commission [8]) specific provisions for a so-called *soft compliance* between the electronic messages which means that rail actors can also use other message types (such as TXT, EDIFACT [9], JSON [10] or similar, and not necessarily XML) as long as the mandatory data elements and message structure from aforementioned TAF TSI data catalogue is respected. ERA was, moreover, mandated to check the soft compliance of such messages vis-à-vis TAF TSI messages in the case of major European rail freight IT implementations projects.

To make the soft compliance (and the exchange of rail transport electronic messages) between the railways within the EU and the neighbouring non-EU countries happen, there was a need to identify which inetrnational organisations group the railways from Serbia, Ukraine, Bielorussia and Russia.

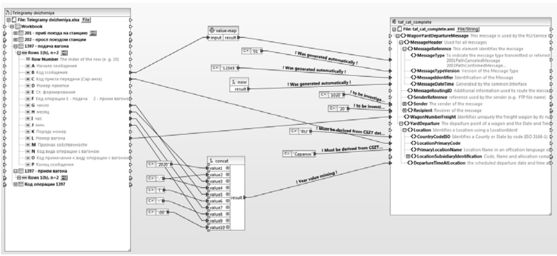
Here the *most straight forward way* to achive such a message transformation was to address this point with the *Intergovernmental Organisation for International Carriage by Rail (OTIF)* [11]. ERA had long and fruitful cooperation with OTIF which resulted at the end of the process in a transposition of the TAF TSI into a so-called *OTIF TAP UTP* [12]. This UTP (Uniform Technical Prescription) is a one-by-one transformation of the EU TAF TSI into the APTU Uniform Rules (Appendix F to COTIF) which is binding regulation within the OTIF member states adhering to this appendix. As for instance Serbia is applying COTIF, the problem of message exchange between the EU and Serbia can be solved relatively easily because on both sides of the border the TAF TSI messages – based on the data catalogue – have to be applied. This leads to the conclusion that the messages used on both sides of ther border are compliant 1 to 1. Another imprortant technical aspect has also been agreed between OTIF and the EU, namely that the TAF TSI UTP will use the same message date catalogue as used in the EU and which is indicated under [6].

On the other hand, a *more complicated set-up* can be observed on the EU external borders with Ukraine, Bielorussia and Russia where electronic message cannot be so easily converted. These countries are members of OTIF but do not apply the TAF TSI UTP. These countries– having established IT systems since decades - are, however, members of the Organization for Cooperation between Railways (*OSJD – ОСЖД* [13]) which has a strong competence in rail freight IT technology and its implementation. A close dialogue in recent years with OSJD enabled ERA to investigate how the electronic message used by the railways in Ukraine, Bielorussia and Russia can be brought to a common denominator wit the TAF TSI messages.

Начало сообщения	Код ссобщения	Код пункта передачи (Саранск)	Номер памятки	Ст. формирования	Код операции 1 - подача 2 - прием вагонов	число	месяц	час	мин.	Порядк номер	Номер вагона	Признак собственности	Код вида операции с вагоном	Код примечания к виду операции с вагоном	Конец сообщения
(:	1397	64160	1256	9883	1	22	10	20	45	15	20457831	1	5	5	:)

Fig.3. Example of OSJD ASOUP 1397 wagon yard departure message [15] before transformation

During this dialogue OSJD and ERA have analised the train operation, train positioning, wagon tracking, consginment and the estimation of train / wagon arrival times. The datiled results of this analysis – including detailed mapping between OSJD and TAF TSI messages – are available at ERA's website [14]. The main conclusion here is that even though the messages used on both sides of the border are quite different (TAF TSI is XML where as OSJD is EDIFACT and TXT) but with an appropriate technical and operational knowledge they can be converted in a soft compliant manner.



```
package com.mapforce;

import javax.swing.UIManager;
import java.awt.*;


public class MappingApplication {
  boolean packFrame = false;

  public MappingApplication() {
    MappingFrame frame = new MappingFrame();
    if (packFrame)
      frame.pack();
    else
      frame.validate();

    Dimension screenSize = Toolkit.getDefaultToolkit().getScreenSize();
    Dimension frameSize = frame.getSize();
    if (frameSize.height > screenSize.height)
      frameSize.height = screenSize.height;
    if (frameSize.width > screenSize.width)
      frameSize.width = screenSize.width;
    frame.setLocation( (screenSize.width - frameSize.width) / 2, (screenSize.height - frameSize.height) / 2);
    frame.setVisible(true);
  }

  public static void main(String[] args) {
    try {
      UIManager.setLookAndFeel(UIManager.getSystemLookAndFeelClassName());
    } catch (Exception e) {
      e.printStackTrace();
    }
    new MappingApplication();
```

Fig.4. Example of ASOUP message transformation into TAF TSI format (with Java code snipet)

Fig. 3 demonstrates again how differently OSJD TXT messages can look – example: wagon event (departure) messages – compared to the the TAF TSI XML ones:

```xml
<?xml version="1.0" encoding="UTF-8"?>
<WagonYardDepartureMessage xmlns:tap="http://www.era.europa.eu/schemes/TAPTSI/1.3" x
    <MessageHeader>
        <MessageReference>
            <MessageType>5016</MessageType>
            <MessageTypeVersion>01</MessageTypeVersion>
            <MessageIdentifier>12345</MessageIdentifier>
            <MessageDateTime>2021-02-26T17:39:18.37+01:00</MessageDateTime>
        </MessageReference>
        <Sender>1020</Sender>
        <Recipient>20</Recipient>
    </MessageHeader>
    <WagonNumberFreight>20457831</WagonNumberFreight>
    <YardDeparture>
        <Location>
            <CountryCodeISO>RU</CountryCodeISO>
            <LocationPrimaryCode>64160</LocationPrimaryCode>
            <PrimaryLocationName>Саранск</PrimaryLocationName>
        </Location>
        <DepartureTimeAtLocation>2020-10-19T17:15:00</DepartureTimeAtLocation>
    </YardDeparture>
</WagonYardDepartureMessage>
```

Fig.5. Example of TAF TSI wagon yard departure message after transformation

Here we can see again that such messages can be transformed into TAF TSI messages only if the concept of *soft compliance* can be demonstrated.

To achieve such soft compliance, the help of data transformation tools is needed. Such data transformation can be seen in Fig.4 whereas the obtained result (say TAF TSI XML wagon yard departure message transformed from OSJD ASOUP one) is visible in Fig. 5.

3. TAF TSI – CONDITIONS FOR IMPLEMENTATION

If we want to keep the deployment and operation of the TAF TSI system in the EU (ensuring at the same time compliance to the IT systems of neighboring non-EU countries) at optimal pace, we will have to think about the corner stones of the system which must be maintained in a unique and non-ambiguous manner.

Firstly, the EU has to ensure that railways, rail infrastructure managers and combined transport actors can use during the message exchange unique identifier for company codes and for primary location codes.

The *company codes* are needed to ensure that we can identify message senders and recipitiens in a unique way. These 4-digit codes should be normally familiar to the reader from the UIC framework. For exampe such a unique and precise company code is '1088' which indicates the Belgian railway. However, its written name could be 'SNCB' (French) or 'NMBS' (Dutch) which cannot be used efficiently in messages as it would create doublets for the company identity. If we consider the billions of TAF TSI message exchanged in the EU per year, this would create a major barrier for operation.

Same holds for the *primary location codes* which are needed in the messages to identify in a unique way the place for which the message has been triggered and sent. A location, for which we could for instance report above wagon yard departure message, could be 'BEOGRAD'. However, bearing in mind the quantity of possible stations in the capital of Serbia it is visible that a primary location code is more precise (not to talk about the possible writing of names with cyrillc or latin characters):

Location	Country	Code
BEOGRAD	SR	16050
BEOGRAD CENTAR	SR	16052
BEOGRAD DONJI GRAD	SR	16051
BEOGRAD DUNAV	SR	16005
BEOGRAD FABRIKA SECERA	SR	16004
BEOGRAD RANZIRNA	SR	16201

Fig.6. Example of different primary location codes in the area of Belgrade

As to guarantee that every company code and every primary location code remains unique in the EU and in the neighboring states, they are centrally stored and updated within the TAF TSI Central Reference File Database at the company called RailNetEurope (https://rne.eu/crd/).

Secondly, the EU also has to ensure that the TAF TSI messages, which are the backbone of the system, remain unique and – if there are needs for updates –packaged within baselines which are backwards compatible. The backwards compatibility is needed because some more advanced rail actors can implement for instance the TAF TSI messages at baseline version 3.2 whereas others are still operating with the older baseline versions 3.0.

In the TAF TSI the ERA is mandated to ensure that those messages are processed in a transparent *change control management process* where technical and economical viability of every update change request is done rigorously. In order to ensure overall benefit and usabilty to the entire rail sector, ERA cooperates within this change control management process not only with railways, rail infrastructure managers and combined transport actors from the EU but also with dedicated experts from OTIF and OSJD. At the end of the change control management process, ERA publishes twice per year the updated TAF TSI technical annexes where the data catalogue with the updated messages is stored [6].

Finally, ERA has to ensure that technical evolution in telematics is also reflected in the TAF TSI. To do so, ERA cooperates with the so coalled rail Representative Bodies [16] and acknowledged experts as to ensure that the updates of the TAF TSI regulation can follow and accommodate new trends and techs in the quicly evolving IT world. The coordination with above Representative Bodies and experts happens in dedicated working parties of the ERA. The ultimate goal of these working parties is to boundle change requests affecting the *legal text* of the TAF TSI regulation and send them as ERA recommendation to the European Commission [17]. Afterwards it is the task of the European Commission to transform the recommendation into EU legislation, say into new version of the TAF TSI (after positive vote of the EU member states).

4. CONCLUSION

The TAF TSI is a regulation within the EU which has been successfully implemented over the years by the European railways, rail infrastructure managers and combined transport actors.

It has also demonstrated that – by using the concept of soft compliance – it can be interfaced with other rail IT systems using different messages, such as the OSJD ones so that rail freight flows can be efficiently set-up and monitored at the Eurasian continent. For the efficient message exchange, the uniqueness of some reference data (company codes and primary location codes) is key.

To keep the TAF TSI regulation at the pace of IT development it is important that the EU (in that case the ERA) works tightly together with the rail Representative Bodies because these actors and their members are operating trains and wagons in their real commercial-operational live. These bodies perform their daily business as front-end towards the freight customers: their experience is needed to see if updates of the TAF TSI legal text are really needed.

ACKNOWLEDGEMENT

The ERA works in the area of the TAF TSI regulation since several years with the Euorpean rail Representative Bodies, OTIF, OSJD and the European Commission. Without their help the TAF TSI and its implementation would not have achieved such good results. ERA’s special thanks go to all of them for the fruitful cooperation.

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COMPARATION OF DIFFERENT RAILWAY LINE CAPACITY CALCULATION METHODS

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Abstract *– One of the basic parameters in the design of railway lines is capacity and therefore its proper dimensioning is extremely important. Whether it is projects of modernization of existing railway line or construction of new one, the key moment is the dimensioning of the planned capacities. As investments in railway capacities are huge and provided from various funds and loans that need to be repaid every year, capacity must be sufficient for a long period of time, sometimes up to 30 or even 40 years in advance. Mistakes made at the design phase can lead to underestimation or overestimation of future capacity, which makes the missed investments. There are several methods used to calculate railway capacities. Each of them has its own specifics, advantages, and disadvantages. This paper will present some of them used on railways in the Republic of Serbia and analyze them on different sections to compare with each other in terms of capacity assessment and determine the differences that arise in their application. For that purpose, one single-track and one double-track section of the railway was observed. The resulting differences will be analyzed.*

Keywords – Capacity, Traffic flow, Capacity calculation method.

1. INTRODUCTION

The capacity of a railway line, or a section of a railway line, represents the ability of the railway to pass a certain number of trains or pairs of trains in a certain period of time, with the existing parameters. The capacity depends on the technical characteristics of the route (gradient, maximum speed, single-track or double-track line), whether the track is electrified or not, the type of signal safety devices, the selected type and series of towing and towed vehicles, the maximum permissible mass of trains, the way traffic is organized. The most common time periods for which bandwidth is calculated are: all day, peak period (2h, 4h, 6h,...), peak hour. The railway capacity can be seen as: [1]:

- Existing (capacity with the existing technical provision of the railway and applied traffic organization)
- Projected (capacity calculated during the design of the railway and technical means and the imagined organization of traffic)
- Necessary (capacity that must ensure the passage of a certain number of trains and other technical means are designed or reconstructed for it).

Methods for determining capacity can be theoretical methods, simulation methods, and parametric models. Theoretical methods for the calculation of railway capacity use relatively simple analytical and/or graphic tools, in order to determine the maximum capacity of a railway line, or section of a railway line, in a simple way, easily and quickly. Considering their simplicity, the obtained results are not extremely precise, but they are precise enough to allow their application in those segments where fast results are needed in relation to the level of precision, often not for the purpose of defining capacity, but for the comparison of several variants of the layout of the infrastructure or ways of organizing traffic. This group includes the classical method, the UIC 405 method and the UIC 406 method. Simulation methods include analytical simulation methods and simulation methods that solve problems using software. Parametric models do not aim to determine the maximum capacity, or even the capacity utilization coefficient, but their primary purpose is to facilitate strategic planning for capacity utilization.

Each of these models has its own advantages compared to other models, but also disadvantages, so

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a single, best method for calculating the railway capacity cannot be adopted.

2. METHODOLOGY

The classic method for calculating the capacity of the railway was created in the middle of the last century. The capacity of one rail depends on the capacity of each individual spatial distance, which do not have to be equal. For the entire railway, that is, the section, the capacity is defined by the spatial distance where the fewest trains can be missed, and as a rule, the fewest trains can be missed on the section where the train arrival time with the required additional times is longer [1]. To calculate the capacity of a single-track line, we distinguish between the most unfavorable inter-station distance and the limiting inter-station distance. The least favorable inter-station distance is the inter-station distance where the sum of the pure driving times in both directions is the longest. The limiting inter-station distance is the inter-station distance at which the graph period is the largest. The graph period represents the time of occupation of the inter-station distance by a group of characteristic train categories. On single-track lines, the graph period is the time required for one pair of dominant class trains to pass, provided that each train is preceded by an opposite train. Below is the basic formula for calculating bandwidth using the classic method.

$$N = \frac{1440}{Tg} \; [pairs\ of\ trains] \tag{1}$$

For double-track line, the capacity is calculated for each track separately, based on the relevant train tracking interval.

In Publication 405-1 from 1979, the UIC proposed a new method for calculating railway capacity. With this method, for the first time, the quality of the transport service is linked to the capacity. As with the classic method, with this method, a limiting inter-station distance is determined for each of the sections. In this case, according to Instruction 70, the limiting inter-station distance is the inter-station distance at which the average time of the minimum consecutive train following is the longest [2]. The capacity of one section is calculated based on the data related to the limiting spatial distance, to which additional time is added for that section of the track, and the parameters of all trains operating on the observed track are taken into account, as well as the relative ratio of trains of different categories. The capacity of the railway section is calculated according to the formula:

$$N = \frac{T}{tsm + tr + td} \; [trains] \tag{2}$$

Where:
N - section capacity,
T – time period for which the capacity is calculated,
tsm – average time of minimum consecutive train tracking,
tr – time reserves (tolerance),
td – additional time.

The average time of the minimum consecutive train following tsm is the average value of the time of the minimum train following which is calculated for all cases of train following on the given track independently or depending on the timetable. The time reserve (tolerance) is the supplementary time provided after each minimum interval of train tracking in order to reduce the risk of chain delays, to maintain the quality of railway traffic exploitation.

$$tr = 0{,}67 * tsm \; [min/train] \tag{3}$$

Additional time is provided after each minimum train tracking interval in order to approximately guarantee the desired quality of service on a certain section. With the increase in the number of spatial sections of the railway and the same requirements for the quality of service provision, the capacity of a part of the railway decreases in relation to the calculated capacity of a given section. At the same time, the approximate value of the correction coefficient of 0.25 min/train per spatial section was determined, and the value of the additional time is:

$$td = 0{,}25 * a \; [min/train] \tag{4}$$

Where:
a – number of spatial sections.

The third method that was used in this paper is the UIC 406 method from 2013, which is an extension of the same method from 2004. The idea of compressing the planned routes, as well as the link between the quality of the transport service and the capacity, is still favored.

The utilization coefficient represents the percentage ratio of infrastructure occupation time, on the observed section (defined section) in the observed time period [3]:

$$\rho = \frac{Tz + Tadd}{T} * 100 \tag{5}$$

Where:
ρ - coefficient of capacity utilization,
Tz - infrastructure occupancy time,
$Tadd$ - additional times (all additional times to increase quality),
T - observation period.

To determine the time of observation, one should take a "representative" day, the peak period in such a day or the peak hour in it. The occupancy percentage is calculated as:

$$\varphi = \frac{Tz}{T} * 100 \tag{6}$$

The percentage of overtime is determined as:

$$\tau = \left(\frac{100}{\varphi} - 1\right) * 100 \tag{7}$$

The percentage occupancy of the infrastructure, taking into account additional (buffer) times, is calculated as follows:

$$\rho = \frac{Tz * (1 + \tau)}{T} * 100 \tag{8}$$

Acceptable level of transport service quality is represented by the percentage of capacity utilization up to and including 100%. Sections with percentage values of occupancy greater than 100% represent bottlenecks and it is necessary to undertake organizational and/or investment measures to increase capacity. Sections with a lower percentage of occupancy than 100% leave the possibility of entering additional train routes on the observed sections.

3. APPLICATION OF METHODS AND RESULTS

For the purposes of this paper, a fictitious section of the railway line A-D, 40 km long, with official places B and C in between, was created, 24 train routes (12 passenger and 12 freight) are drawn in the initial timetable chart. The limiting inter-station distance is B-C, 14 km long. The time period for which the calculations were made included a peak period lasting 6 hours. Figures 1 and 2 show two-hour segments of the single-track line and double-track line timetable charts.

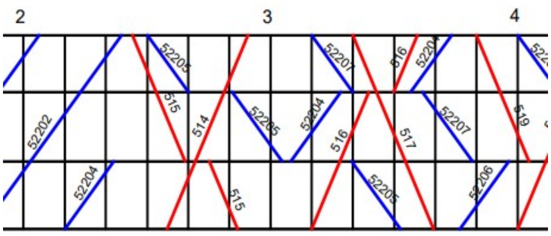

Fig. 1. Single-track line

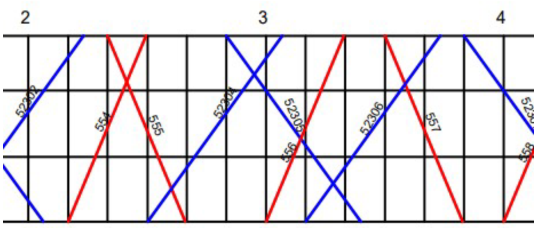

Fig. 2. Double-track line

Based on the initial graph, the methods for calculating capacity were applied, namely the classical method, the UIC 405 method and the UIC 406 method.

Using the classical method, a value of 21 trains was obtained for maximum capacity utilization of 100%. Using the UIC 405 method, this value is 20 trains, and using the UIC 406 method, it is 24 trains. The following figure 3 shows these results.

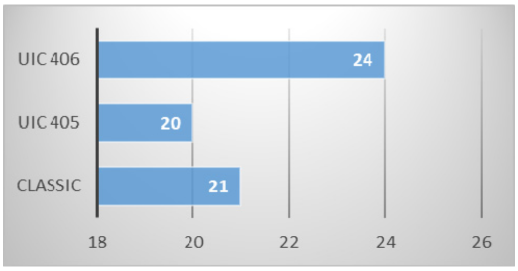

Fig. 3. Single-track line (maximum number of trains at 100% capacity utilization, in 6 hours)

The lowest value with the UIC 405 method is because the schedule of trains was such that passenger and freight trains went alternately, so it was necessary during compaction to allow an interval long enough to enable maximum traffic safety. The UIC 406 method gives the best results in this case. Figure 4 shows a comparative view of infrastructure occupancy after route compression, expressed in percentages. Only these two methods were compared, for the reason that the classical method is not based on the compression of routes.

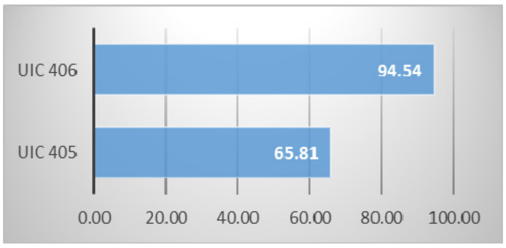

Fig. 4. Single-track line (occupancy of the compressed timetable infrastructure in percent, for 6 hours)

The UIC 406 method shows a significantly higher occupancy because it takes into account, when compressing the routes, the entire section (A-D), unlike the UIC 405 method that uses only the limiting inter-station distance (B-C).

When it comes to a double-track line, the application of all methods is significantly simpler. The reason for this is that the capacity is calculated for each track separately. It is important to calculate an adequate interval of following consecutive trains, so that there is no collision of overtaking trains. Figure 5 shows the percentage occupancy of the infrastructure by 12 trains from the schedule chart (6 passenger and 6 freight) for one track. For the second track, the situation is exactly the same, given that the train times are the same in both directions.

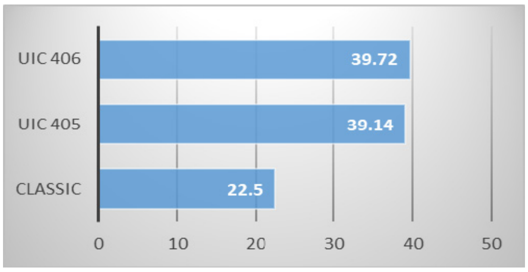

Fig. 5. Double-track line (percentage capacity utilization for 12 trains from the initial timetable, in 6 hours)

In this case, the classical method proves to be the least busy. The reason for this is that the relationship between the observation time and the follow-up interval is observed. The additional times that guarantee a better quality of the transport service are not taken into account, unlike the UIC 405 and UIC 406 methods, which is why they have higher values. Observing the number of trains that can pass through the railway at maximum capacity, it is observed that the classical method gives the apparently best result, which is because no additional (buffer) times are used. The equal number of trains for the UIC 405 and UIC 406 methods shows that taking into account the additional times to improve the quality of service, there is necessarily a reduction in the maximum number of trains (Figure 6). The equal number of trains in these two methods is consistent with the values shown in Figure 5.

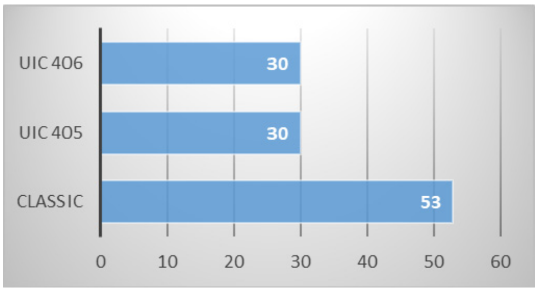

Fig. 6. Double-track line (maximum number of trains at 100% capacity utilization, in 6 hours)

4. CONCLUSION

Calculation of capacity is a very important part when designing a new railway line and/or reconstruction of existing ones. It is for this reason that different methods for capacity calculation have been developed. First, the classic method was developed, which is still used in some countries today. Its advantage is reflected in its simplicity, as well as in the fact that it does not have to use the existing timetable. With this method, the capacity can be increased by organizing train traffic in bundles. Shortly after the classical method, UIC developed a method called the UIC 405 method. This method is still valid on Serbian railways. It also takes into account the quality of the transport service as an important factor. It is based on the compression of train routes and the addition of time reserves to maintain quality. Years after that, UIC developed the UIC 406 method. This method is very similar in principle to the UIC 405 method. It takes into account quality and additional times, but also looks at the whole section unlike UIC 405. None of these methods can be labeled as the best, but each has enough advantages and gives good enough solutions that it can be used. That is why all three methods are still in use.

In this paper, a peak period of 6 hours was observed, so for the all-day capacity, all values should be multiplied by 4. The results at maximum utilization are also shown, which represents an extreme value. The recommended utilization values are around 75%, where the time required for regular maintenance of the infrastructure should also be taken into account, which was not considered.

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XX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
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OPTIMIZATION OF TRAIN OPERATIONS AT PANCEVO M.S. RAILWAY STATION USING OPENTRACK

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Jelena MIŠKOVIĆ[2]

Abstract *– The aim of this paper is to present solutions to the problems that occur in Pancevo M.S. while managing trains running on the diverted route. Rescheduled or diverted trains occur for various reasons. Due to the reconstruction of the railway line between Stara Pazova and Novi Sad, diverted freight trains have been operating through Pancevo M.S. for several years. To manage the increased traffic volume at the station, a new plan of operation and technology of work was developed. The plan was optimized using the OpenTrack simulation tool.*

Keywords – Train operations, Railway station, Optimization, Simulation, OpenTrack.

1. INTRODUCTION

Timetable scenario planning and construction, i.e., scheduling, is the most difficult and demanding task and business challenge for railway traffic planners. The challenge is growing, and the difficulty increases if some of the infrastructure elements unexpectedly stop functioning or if their operation is interrupted for any reason. As a result, speed limitations or reductions on the line or on station tracks are required in the short or long term. But the most demanding task for planners is solving a problem when they are faced with trackworks that must be done with part-time or total closure of the railway line or section of the line.

The total closure of one railway line has an impact on traffic operations on the railway network as a whole.

If track works have to be done with a total closure of the line lasting one or more years, schedulers must look at and analyze large-scale datasets to determine the best options for optimizing the annual traffic plan. While making such a traffic plan, schedulers must take into consideration the possibility that trains are allowed to run on one or more diverted routes.

Some alternatives have to be presented for selecting the optimal train route. If there is only one feasible diverted route, then all constraints should be thoroughly and carefully considered.

The problem of making train route decisions during track works and modeling trains running on the diverted route was widely discussed among traffic planners. In scientific publications, a variety of approaches, strategies, and models for supporting decision-making on this issue were presented.

Some strategies are based on total cancellation of the train schedule during works on the railway line, and some are based on partial cancellation of the train schedule at the beginning, in the middle, or at the end of the itinerary of the train service, detour service, and delay/ahead of time scenarios, etc. [1]. Models applied that support decision-making varies from analytical, graphical, statistical, and mathematical to modern simulation models.

This paper discusses the train scheduling problem during the total closure of a section of line for a couple of years between railway stations Stara Pazova and Novi Sad due to reconstruction and upgrading of the line. The section is a part of the magistral electrified line No. 105 (Belgrade) Stara Pazova-Novi Sad-Subotica-National border with Hungary (Kelebia). The work on the line was finished in March 2022. The line is currently open for passenger traffic. The beginning of operations of freight trains is planned for the end of 2022.

The official traffic strategy for scheduling on the line is based on two premises, such as:

- partial cancellation of the passenger trains schedule at the beginning of the itinerary between stations Belgrade Center and Novi Sad, and a new delay/ahead of time scenario between stations Novi Sad and Subotica; and
- freight train scheduling on the diverted route between stations in the Belgrade railway node and Novi Sad railway node via stations Pancevo Main Station (M.S.) and Orlovat.

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The primary focus of this project is how to manage the increased traffic volume at the Pancevo M.S., and create an efficient operation and technology work plan for the station. For the decision-making support in developing and optimizing such a plan, the OpenTrack simulation software was used. The simulation method has been confirmed as an excellent tool for monitoring and analyzing the relationship between traffic volume and traffic infrastructure capacity.

2. TOPOLOGY AND MODELING OF THE PANCEVO RAILWAY NODE

The Pancevo M.S. is a major and most important station in the Pancevo railway node (PRN), which consists of 3 stations, 1 railway stop, a triangle, and 3 connection lines with industrial railway tracks, Fig. 1.

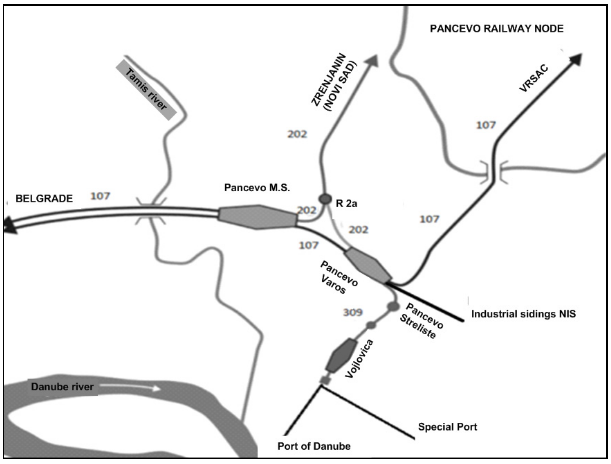

Fig.1. Scheamatic view of the Pancevo railway node

The Pancevo M.S. and the Pancevo Varos station lie on the magistral railway line No. 107, which is an electrified double-track line from Belgrade Center till Pancevo M.S. and an electrified single-track line from Pancevo M.S. till Pancevo Varos. The rest of the line till Vrsac station is a nonelectrified single-track line.

The Pancevo M.S. is a connecting station for the regional single track railway line No. 202, and Pancevo Varos is a connecting station for the local single track railway line No. 309. Furthermore, the Pancevo M.S. is a marshaling yard and a dispatch station for the 8 dispatching sections.

The Pancevo M.S. has 22 station tracks. Among them, 5 are reception/departure sidings and 9 are train-formation sidings.

2.1. Simulation Methodology

A methodology in general can simply be described as a series of steps to follow. Since simulation involves system modeling based on the general precepts of solving a problem through system analysis, the simulation methodology steps can be stated as follows:

1. Identification and formulation of the problem;
2. Conceptual model development;
3. Choosing and preparation of input data for modeling;
4. Selection of a simulation tool and developing a simulation model;
5. Determination of simulation duration;
6. Running a preliminary simulation (simulation status zero) to calibrate, verify, and validate the model;
7. Planning and performing simulation experiments;
8. Exploitation of the simulation model (for analysis of a variety of scenarios or to generate alternative solutions);
9. Analysis and evaluation of the simulation results;
10. Presentation and interpretation of simulation results to decision-makers (text, graphics, tables, and animation) [2], [3].

2.2. Problem formulation

The problem that was identified in Pancevo M.S. is high occupancy of reception/departure and train-formation sidings for freight trains, especially after rescheduling freight trains running on the diverted routes. There was an assumption and a real fear that, if freight traffic volume on the diverted route continued to rise, this station would become a bottleneck on the line.

At this station, transit trains running on the diverted route have to stop for technical reasons, i.e., for locomotive change (electrical/diesel or vice versa), change of the position of a locomotive on the train, etc. In some cases, some commercial and other technical operations with the trains are needed.

2.3. Input data and simulation tool

For the modeling, the following boundaries of the model are determined:

- Home signals of the Pancevo M.S. from Ovca station (Vu92 in km 19+092 and Vu 94 in km 19+000);
- Home signal of Jabuka station from Kacarevo station (km 22+757);
- Home signal of Bantsko Novo Selo station from Vrsac station (km 34+930)
- Home signal of Pancevo Varos station from industrial sidings NIS (Au in km 0+783);
- Home signals of Pancevo Vojlovica station from industrial sidings Special Port (Du in km 3+250) and Port of Danube (Bu in km 3+246);

Input data are:

- infrastructure elements data (longitudinal section of the lines, characteristics of 38 tracks in 5 stations, 76 switches, 8 level crossings, 76 signals, electrified area, permitted speed on tracks, and speed restriction areas);

- technical characteristics of locomotives, EMUs, DMUs (series 711, 641, 647, 667, 060, 733, 742, 733-033, DA060 and 060);
- trains characteristics (mass, length, traction vehicle, category, etc.);
- course itineraries and timetable 2019/2020;
- duration of commercial and technical operations; time norms of the technological processes in stations; traffic operational rules, etc.

OpenTrack simulation software was chosen as a simulation tool [4].

2.4. Simulation model development

The simulation model of PRN consists of 1557 infrastructure elements with 7708 data (730 vertices with 1576 data, 729 edges with 5832 data, and 92 signals with 276 data). The Pancevo M.S. model is presented in Fig. 2.

running only between PRN stations;

- all freight trains for industrial purposes start/end their movement at Pancevo Varos station.

Fig. 3 shows the train departure from Pancevo Varos.

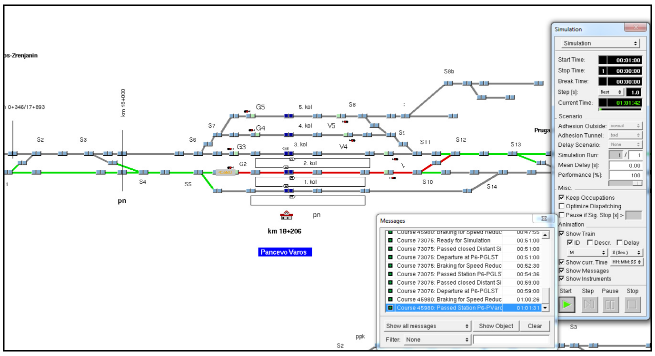

Fig.3 Train No. 45980 departs Pancevo Varos

2.5. Calibration, verification and validation of the simulation model

The model was verified by zero simulation and it

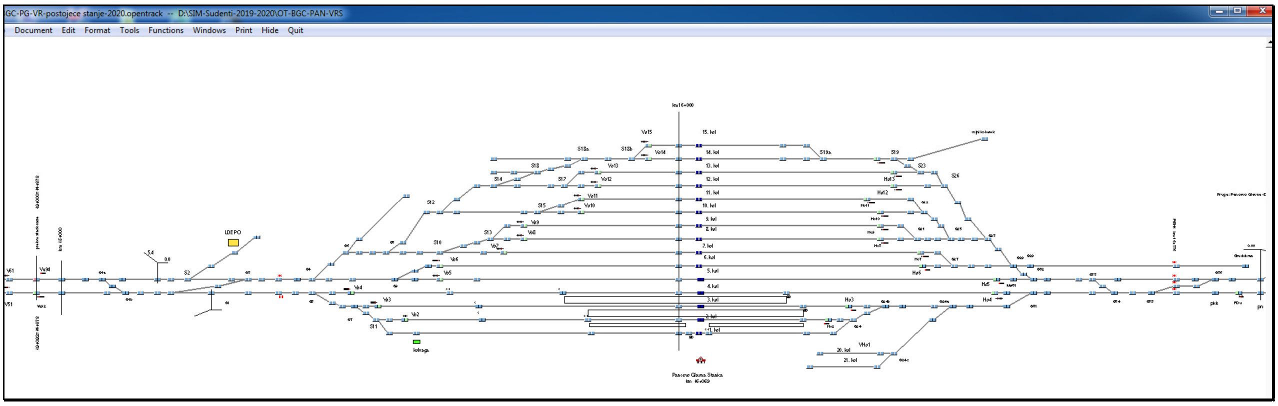

Fig.2 Model of the Pancevo M.S. in OpenTrack

For the train movement and safety system, it is defined 195 Routes, 279 Paths, and 132 Itineraries.

It was used: Module Depot for modeling all traction vehicles, module Trains for modeling 46 different composition of trains with 368 data, and module Courses for modeling 109 courses with 504 data.

During Itineraries and Courses modeling, the following rules were taken into consideration:

- all passenger trains are in transit;
- some freight trains in transit pass through without stopping; some trains stop but do not change composition; some trains stop to change locomotive (electrical to diesel or vice versa); and some trains stop for changing locomotive position on the train and movement direction;
- PRN stations are the origin and destination for some freight trains; some freight trains are

was determined that the model behaves according to all the principles and rules that are valid in railway traffic. The infrastructure elements (signaling devices, position of switches, occupancy and release of routes) behave identically to a real system. Train movement is along the given basic or alternative itineraries.

The zero simulation experiment was performed several times in order to verify the functionality of the model and the identity of the output results. The simulation was done for good, normal, and bad conditions of exploitation (adhesion). No calibration of the model was needed.

For validation of the model, the simulation results were compared with the real data obtained from the traffic operation authorities.

3. SIMULATION EXPERIMENTS AND RESULTS

Since the time when freight trains started to run on diverted routes, the number of trains in the Pancevo M.S. has risen by around 40% (38 trains).

For simulation experiments, a few scenarios were established:

- Scenario 1- simulation of all regular trains in 24 h;
- Scenario 2 - simulation of all regular and facultative trains or ad-hock trains as they occur - 7 days simulation;
- Scenario 3 - simulation of all trains running on the same day.

The official organisation and technology of work of each station were followed due to examine their correctness and efficiency.

The main focus was on Pancevo M.S.`s organisation and technology of work.

The technological processes in Pancevo M.S. were monitored for two sets of time norms: classical time norms and newly introduced time norms established by the station technology planner (the time norm for all operations with trains is 30 min).

3.1. Simulation results

The simulation results of train operation are given for two different approaches to station technology of work.

Operation and technology with classical time norms indicate the following:

- Scenario 1 - all regular trains operate without conflicts;
- Scenario 2 - four conflicts occur (some trains wait to enter the station because the reception tracks are occupied);
- Scenario 3 - full congestion of the station with many conflicts.

Operation and technology with a time norm of 30 minutes indicate the following:

- Scenario 1 - all regular trains operate without conflicts;
- Scenario 2 - four conflicts occur (some trains wait to enter the station because the reception tracks are occupied);
- Scenario 3 - 18 conflicts are identified.

Conflicts are classified as follows:

- Stop at home signal - reception track is occupied (6 trains);
- Wait on station track - shunting is not possible (2 trains);
- Generation of a train is not possible - station track is occupied (6 trains);
- Wait at exit signal (2 trains);
- Arrival planned at the same time at the same track from the opposite direction (2 trains);

All conflicts were solved by rescheduling. New technology of work for the station was determined.

Occupancy of reception/departure sidings are 25% to 50% and train-formation sidings from 65% to 90%.

4. CONCLUSION

Traffic simulation is a widely used method and an important tool applied in the research on railway traffic. It enables planners and schedulers to use budgets and resources as efficiently as possible, saving time and helping to avoid experiments in real system.

Simulation models help to understand the effects that different measures have on traffic volume and flow under different circumstances. Traffic simulation results create a solid basis for cost-effective decision making.

The modeling and simulation presented are important to determine the operational efficiency of stations while trains run on the diverted route. This model can be used for other traffic scenarios and can be upgraded for other purposes.

ACKNOWLEDGEMENT

The infrastructure simulation model of the Pancevo railway node (PRN) was developed in 2021 within the project for the Master`s thesis of one of the author [5].

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XX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
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TRAFFIC SIMULATION ON THE PART OF THE RAILWAY LINE FROM PANČEVO MAIN STATION TO VRŠAC STATION AND STAMORA MORAVITA BORDER

Nataša PEJIĆ[1]

Abstract *– Transport services are the basic logistical support for human and economic activities. For the planning of the elements of transport service quality, timetable planning is of primary importance. In this paper it is presented, simulation of railway traffic in order to examine the limiting factors and possible technological reserves on the part of the railway line from Pančevo main station to Vršac station and Stamora Moravita border. For the modeling railway infrastructure, train composition and trains were used Open Track software. The results of the simulation are presented on a train graph.*

Keywords – traffic simulation, 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.

Within the planning of elements of the quality of the transport service, planning the timetable is of primary importance. 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 application of railway traffic simulation software "Open Track" for the creation of a simulation model 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 Pancevo Main station – to Vršac station – Stamora Moravita border for the timetable 2020/2021. year.

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

2. MODELING OF THE SIMULATION MODEL ON THE RAILWAY NETWORK FROM PANČEVO MAIN STATION TO VRŠAC STATION AND S. MORAVITA BORDER

Modeling and simulation were performed according to simulation methodology phases as follows:

- Phase 1. Definition of the problem;
- Phase 2. Designing the study;
- Phase 3. Designing the conceptual model;
- Phase 4. Formulating inputs, assumptions, and process definition;
- Phase 5. Data collecting, separating, selecting and preparing;
- Phase 6. Choosing the simulation tool, simulation language or simulation software;
- Phase 7. Building and verifying the simulation model;
- Phase 8. Calibrating and validating the simulation model;
- Phase 9. Simulation experiments planning (scenarios planning);
- Phase 10. Exploiting the simulation model (experiment with the model), performing the simulation by defined scenarios;
- Phase 11. Analyzing the simulation results;
- Phase 12. Presenting the simulation results and
- Phase 13. Defining the model life cycle.

2.1. Features of "Open Track" simulation software railway traffic

Open Track is a software program for the simulation of rail traffic on a railway network that was developed as part of a research project called "OpenTrack – Simulation of railway networks", of the Swiss Federal Institute of Technology - Institute for Transport Planning and Transport Systems (ETH IVT). This software enables the creation of macro-

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simulation models with all the elements of micro-simulation models, that is it enables the modeling of the railway network without restrictions in size with all elements of the highest level of detail.

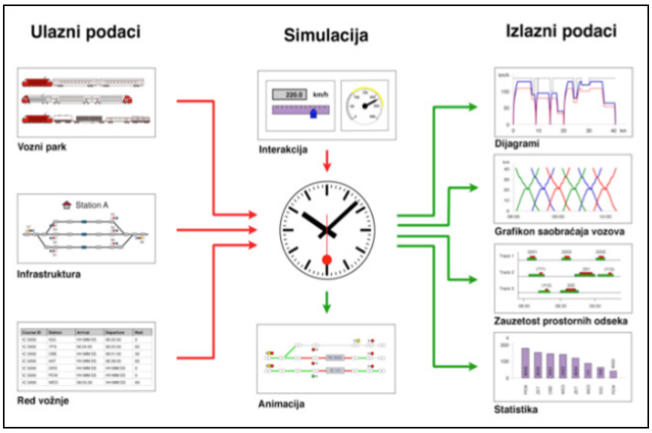

Fig.1. Open Track processes: Input-Simulation-Output

This software enables parallel discrete and continuous simulation with stochastic state changes.The basic input data for creating a model in "Open Track" are:

- Data on vehicles;
- Information about infrastructure;
- Information about the timetable;

2.2. Topology of the railway network from Pančevo main station to Vršac station and Stamora Moravita border

On the part of the railway network from Pancevo Main station to Vršac station and Stamora Moravita border in terms of technical and operational characteristics, there are 10 official places, of which 2 stops, 1 crossing and 7 stations. Also, this part of the railway network is 66.7 km a long.

Fig. 2. Railway network of railway infrastructures Serbia - situational view of the railway section from Pančevo Main station to Vršac station and S. Moravita border

Railway network from Pančevo Main station to Pančevo Varoš are electrified with the AC traction power supply system of 25 kV and 50Hz. While part of railway network from Pančevo Varoš station to Vršac station and Stamora Moravita border is not electrified.

Maximum permitted speed on part of railway network form Pančevo Main station to Vršac station we could see in tab 1. From the table it can be seen that the maximum permitted speed allowed from Pančevo Main station to Pančevo Varš station is 50km/h, while on rest part of this railway network maximum permitted speed is 100 km/h.

Tab 1. Official places on railway network from Pančevo main station to Vršac station

Official place	Maximum permitted speed on the railway (km/h)
PANČEVO MAIN STATION	50
Pančevo Varoš	
Banatsko Novo Selo	100
Vladimirovac	
Alibunar	
Banatski Karlovac	
Nikolinci stop	
Uljma	
Vlajkovac stop	
Vršac	

Source: timetable booklet for the timetable 2020/2021. year for railway network 6.1.

2.3. Definition of a problem

The problem under consideration is the ratio of the planned volume of traffic for timetable 2020/2021. year and the existing infrastructure capacities on the part of the railway network from Pančevo Main station to Vršac station and Stamora Moravita border, 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 Pančevo Main station to Vršac station and Stamora Moravita border, 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 the station Pančevo Main station to Vršac station and Stamora Moravita border, after the reconstruction, the capacity of some official places was reduced, but regulation technology of the traffic wasn’t changed. 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 Pančevo main station to Vršac station and Stamora Moravita border, which predicted an increase in requests for traffic operations, as well as an increase of shunting work in stations.

2.4. Modeling infrastructure

Before modeling the infrastructure, data about infrastructure and signals box was collected from the real system. After data collection, was made systematization and preparation of data for entering the software. This simulation model was made from 1,938 infrastructure elements into which 10,457 data were entered, namely:
- 916 vertices with 2786 data;
- 921 edges with 7368 data;
- 103 signals with 309 data;

Nine official places were entered into the database station, the characteristics of which were modeled with a total of 36 data. Pančevo Main station is included in the traffic simulation model for the purposes of this work, but it was modeled for the purposes of traffic simulation in the Pančevo railway junction.

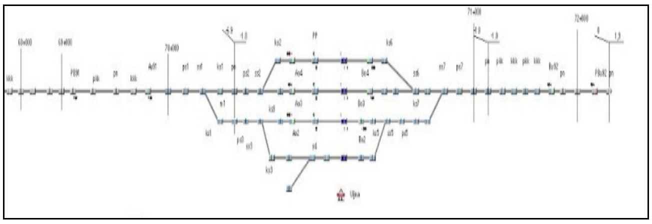

Fig.3. Uljma station and tracks layout in OpenTrack

2.5. Modeling locomotives, motor units and composition of trains

Modeling of towing vehicles is done through the "Engines" editor, and the data is stored in the database "Depot". A total of five types of towing vehicles were modeled. These are: electric locomotive of series 441 and 461, diesel locomotive of series 647, diesel-electric locomotive of series 661 and diesel-motor train of series 711 (DMU 711). Composition of freight trains have been created by selecting one locomotive from the locomotive database and combining it with length and weight data of freight wagons. Passenger trains have been created by DMU 711, due to on this railway section only traveling DMU 711. For train's motion, proper formulas with their values were assigned to each train.Also, acceleration and breaking values were assigned to each train as well.

2.6. Modeling courses and timetable

Timetable data consists of information on the movement of trains. This information includes desired arrival and departure times, connection information, minimum stop times.
In this study have been modeling of 34 regular trains per timetable for 2020/2021. year. Modaling have been across database, "Courses", modeled are 12 passenger trains (6 pairs of passenger trains) and 22 freight trains that operate regularly. Modeling of trains have been by first defining the number of trains in the window for trains ("Courses"), then adding an Itinerary from the database "Itinerary" to the train, then adding the composition for the train from the database "Trains". After that have been selecting the rang of the train and entering timetable elements (time of generation or arrival, time of operation and time of departure from the starting station).

Within the framework of the model, it was determined:
- 194 routes;
- 74 paths;
- 42 itineraries;

3. SIMULATION AND SIMULATION RESULTS

For a validation of a model, a simulation has been performed. The results showed that actual timetable data and simulation data of train movement through the model are correspondent. The model was verified for exploatation.

Simulation was performed for one day (24 hours' time) including 34 trains that regularly travel on the railway section from Pancevo Main station to Vršac station and Stamora Moravita border. The simulation results are presented on a train graph divided into two graphs of 12 hours' time intervals. These graphs of them are presented in figures 4 and 5.

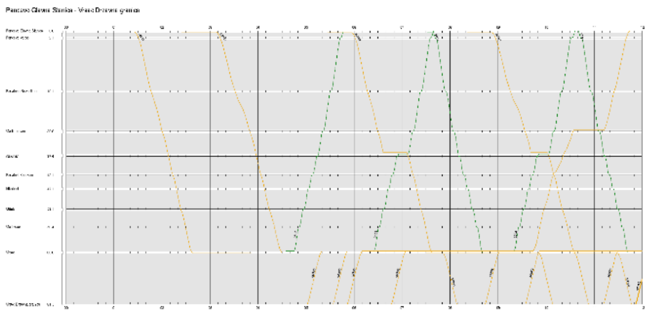

Fig.4. Train graph from 00:00 to 12:00

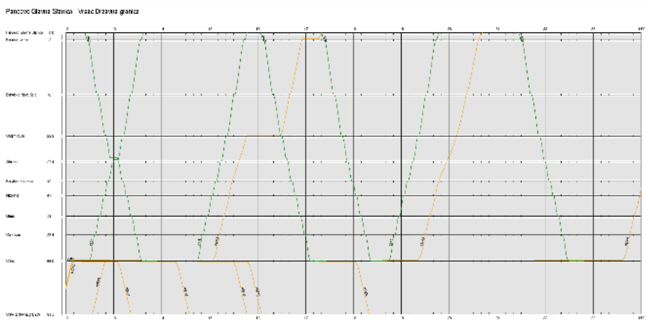

Fig.5. Train graph from 12:00 to 24:00

4. CONCLUSION

The analysis of the results obtained by the simulation determined, that the capacities on the part of the railway from the Pancevo Main station to Vršac station and Stamora Moravita border for the defined traffic organization of the predicted number of trains that regularly operate according to the planned timetable 2020/2021. year and station operation technology satisfactory (there aren't "bottlenecks" on the infrastructure).

On the other hand, the results indicated that the traffic scenario according to timetable for 2020/2021. year has shortcomings in relation to the maximum permitted length. Primarily, the Vršac station has a small number of tracks which can be accept trains with maximum permitted length according to the timetable.

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A MODEL FOR IMPROVING THE QUALITY OF RAILWAY TRANSPORT SERVICES BASED ON ADVANCED INTERNET

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Abstract *– One of the issues of providing and quality of transport services in the railway company is becoming more and more interesting for users as well as for researchers in the field of traffic and transport. The solution can be the use of advanced internet technologies. The application of innovative internet technologies is increasingly present in railway companies. The railway service provider has a developed infrastructure and architecture in its business, which is not sufficiently used in the passenger transport segment. The basic expectations of the users (employees and students who use railway transport on a daily basis) refer to the purchase of a transport ticket in the shortest possible time, as well as the payment of the same year-round. This paper presents a comparative analysis between the traditional and digitalized process of purchasing and purchasing a transport ticket. The model includes the existing computer network and smartphones. The main goal of this paper is to present an information and communication model (ICT) based on advanced Internet technologies that meets the wishes and needs of service users and also improves the image of the railway company with higher revenues.*

Keywords – railway transport, service user, innovative IT model, digitalization of business processes.

1. INTRODUCTION

The application of advanced Internet technologies has a large share in the internal operations of transport companies. At the same time, it is increasingly represented in processes and activities directed towards service users. Informatics and computer networks from a technical aspect represent the starting point for the realization of a large number of activities in the shortest possible period of time from any place [1],[2],[3],[4].

In this paper, on the basis of previous research, a comparative analysis is presented between the traditional way of doing business (the user going to the office of the transport carrier) and the information technology (IT) model, which includes the user and the service provider. Comparative analysis includes situational parameters (space, time, roles, relationships, interactions, environment and service) that differ in many ways in business models. The next step is to determine the attitude of users who often or daily use the services of the transport company. And finally, an innovative IT model that includes the service user's smartphone and the railway company's service.

2. RELATED RESEARCH

At Digitization of business processes is a great challenge and opportunity for the improvement of railway passenger transport. Through a detailed analysis of the existing state of the railway passenger traffic system, a logical structure and functional framework of a dynamic electronic business system based on Web services and RFID technology was designed, with the aim of developing railway

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passenger electronic business. Taking into account the current situation of the railway ticket system and the characteristics of the operation of the future line intended for passengers, and the system of dynamic electronic business of railway passengers becomes more efficient and costs are reduced [5].

The analysis of the basics of railway informatization and the actuality of the application of railway electronic business shows the problems that need to be solved in electronic business. In order to solve these problems, a new strategic model was given. The architecture based on the general technological platform and the implementation framework of e-business on railways are presented. Finally, it is suggested that the process of building an e-business system be divided into three phases and that the goal of each phase be defined [6].

Many different solutions have been implemented in the past. But in the last few years, a new type of solution has emerged: mobile ticketing. This ticketing concept uses users' mobile devices to purchase tickets for public transportation, instead of separate devices owned by the carrier. Another topic of conversation in mobile technology is location-based services, which are services offered through a user's mobile device based on their actual location [7].

To reap the benefits for both the passengers and the railway undertaking, a smart ticketing system with user authorization, seat reservation, online payment and destination announcement system is also necessary for a railway based transport system [8].

The mobile revolution has reshaped people's lives, providing not only communication but also basic financial access in the form of phone transfers and money storage. With the emerging innovations of mobile technology, the use of mobile phone as a virtual device for online transactions has surpassed the effort to invest in physical transactions as the mobile phone is used with great versatility in our daily life, the use of this technology in the transport sector through the ticketing process would be great supporting thousands of commuters who move to and fro for a living [9].

3. COMPARATIVE ANALYSIS OF THE TRADITIONAL AND IT MODEL OF TICKET PROCUREMENT

Modern business requires the application of advanced Internet technologies.

Tab. 1. Comparative analysis of parameters of traditional and IT business models

Model Situational parameter	**Traditional model**	**IT service model**
Space	Passenger cash desks in railway business facilities authorized for ticket sales and direct communication between interested parties	Virtual cashier (service provider) based on IT business (selection and payment of service, obtaining a digital record representing an e-ticket)
Time	Limited daily working hours of passenger cash desks in railway facilities	24 hours a day, seven days a week to choose and pay for the service with a digital ticket
Roles	Service user with need, request and expected ticket service / service operator (realizer of direct distribution)	Ordering, selling and delivery of the requested service through the railway service in IT business with the service user
Relations	The user of the service in f-f communication with the cashier in all transactional activities	IT communication between the user of the service and the railway service in the digital activities of ordering, paying and obtaining a transport ticket in a digital record with the service seeker
Interactions	User of the service with employees in the passenger ticket office	Mutual interaction between the user of the service and the railway service for ordering, buying / selling and owning the ticket
The environment	Physical access of the user to the ticket office / work space for the employee of the railway company	An innovative platform for digital business between service users and railway services for choosing, paying and receiving a ticket in a digital record
Service	Transportation ticket in paper form	Electronic ticket in digital record

In contrast to the above, the traditional model of purchasing transport tickets implies additional user activities that are limited by the working hours of the ticket office in the facilities of the railway company, the spatial distance from the place of residence to the premises of the railway company whose main purpose is the sale of transport tickets, the time required for the realization of the activity of purchasing transport tickets maps and the interaction that takes place between stakeholder.

The IT model includes and at the same time solves all the mentioned potential problems by applying advanced internet technologies, where activities are digitized through computer networks, hardware and software of service providers and users in order to acquire an electronic ticket. Table 1 shows a comparative analysis of the basic situational parameters (space, time, roles, relationships, interaction, environment and service), where a drastic difference between the traditional and IT business models can be seen.

4. ANALYSIS OF USER ATTITUDE BETWEEN TRADITIONAL AND IT MODELS

In addition to considering the real needs of service users for the application of the IT model of electronic business, a survey of service users was carried out as well as statistical data processing.

Research methodology includes [10],[11].:
- Realization - Field research;
- Type of research - Surveying;
- Sample size - 91 service users,
- Target population - students and employees.

Tab. 2. Statistical data processing

IN TOTAL		
N	Valid	91
	Missing	0
Mean		99.8022
Median		101.0000
Mode		104.00[a]
Std. Deviation		5.98743
Variance		35.849
Skewness		-.499
Std. Error of Skewness		.253
Kurtosis		-.691
Std. Error of Kurtosis		.500
Minimum		85.00
Maximum		109.00

Figure 1 shows the frequency distribution of responses for 91 service users.

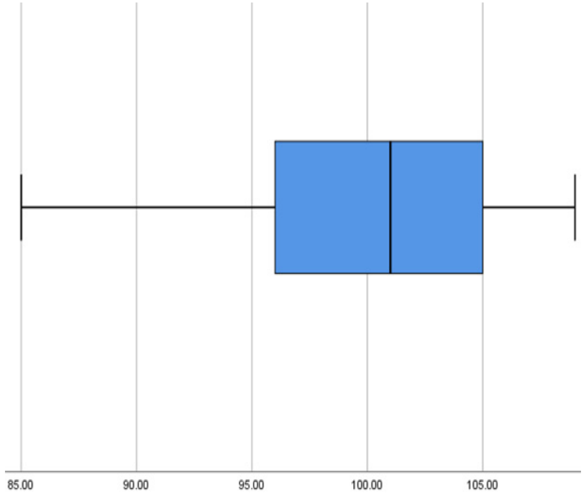

Fig.1. Box plot display for service users

A box plot shows a quantitative variable, where you can see the box representing 50% of the results (from the left to the right edge of the box). The solid line running along the box represents the median. From the box you can see the five-digit data where the distribution is asymmetrical, where the entire box is shifted to the right. The five-number summary includes a minimum score of 85, a 25 perceptile of 96, a median or 50 perceptile of 101, a 75 perceptile of 105, and a maximum value of 109 [10].

5. DEVELOPMENT OF AN IT BUSINESS MODEL

The modeling of the architecture of the IT transaction model is based on the analysis of the interactions of five components of the whole that represent the modern paradigm of business processes (applied technology, organizational processes, environment, human resources and service or product) [1],[12],[13],[14].

The architecture and infrastructure of the IT business model includes the technologies of the virtual environment that is based on the Internet (Figure 2.). In the virtual environment, the service user interacts with the service provider, the railway company, without limitations in time and space. The user of the service on a smartphone with an internet connection performs an overview, selects the requested service, pays and receives a confirmation from the service provider that the monetary transaction has been successfully completed via the network.

Computer technologies as well as organizational processes predict certain rules in advance in order to realize the activities that the user of the service requires while the service provider's service has the active supervision of the IT administrator.

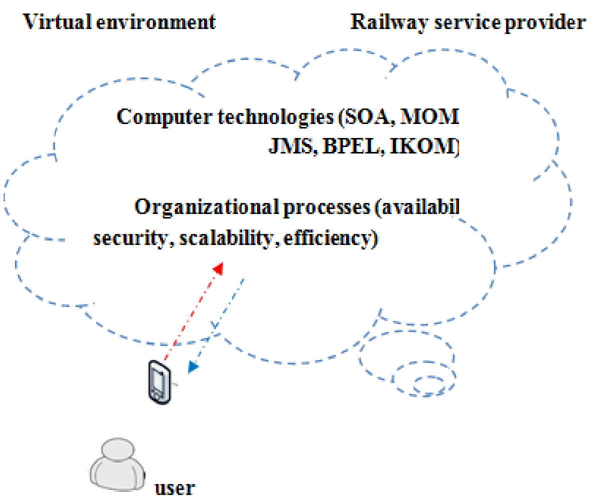

Fig.2. Architecture of the IT model

6. CONCLUSION

This paper presents an innovative IT business model that is realistically acceptable because a large number of people use smartphones in their daily activities. In its internal operations, the railway company already has a developed infrastructure that needs to be upgraded with small financial investments.

The comparative analysis showed essential differences between the traditional and IT models, where the prerequisites for digitalization of all activities through computer networks in the railway company are created. The attitude of the surveyed users towards the innovative IT model is positive and at a high level. Only students and employees (91.) who voluntarily agreed, who use railway services every day and own a smartphone, were surveyed.

At the end, the basis for modeling and developing innovative business models is presented, where the user of the service stands out in the foreground. Future research should include testing and implementation of the service, as well as integration with other businesses.

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Infrastructure

RAMS CONSIDERATIONS OF COMPUTER BASED INTERLOCKINGS DURING THEIR LIFETIME CYCLE IN PRACTICE

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Abstract *– This paper deals with the reliability features of various Computer-Based Interlocking - CBI systems in light of their lifetime cycle introduced by the CENELEC railway standards. During the 40 years of application CBI systems have been following and using the technological advancements related to electronic hardware. As a result, CBI systems use different hardware with various generations of processors and consequently, have varying reliability characteristics. All CBI systems have to have a very high Safety Integrity Level - SIL and high availability introduced with the well-known RAMS concept of CENELEC railway standards. Two out of three, or two times two out of two, the architectures of both the central CBI computer and the area control computers significantly improve the availability of the CBI. The high degree of modularity of CBI systems offers scalability and the ability to equip the entire range of stations, from very small stations to large nodes, or sections, with over 1000 points and signals. During the evolution of CBI systems their control modules have experienced a higher degree of integration,which has contributed to the minimisation of the design, installation and testing time. Also, new technological advancements are used and applied during the realization of all CBI modules, hence contributing to their increased reliability. The MTBF values of the modules of CBI systems that have been produced more recently and are in use today are several times higher than the MTBF values of some other systems realized in earlier times. Although all CBIs are mostly comparable from the safety and availability point of view, they may significantly differ from the reliability point of view. The safety and availability characteristics of a CBI are usually required, considered and evaluated at the time of purchase, but the reliability requirements are often omitted. This approach can cause significant unforeseen costs during the long lifetime of a CBI. The purpose of this paper is to show how much an interlocking system really costs during its lifetime and to demonstrate the advantages of highly reliable CBIs from that point of view. The monetary savings related to the amount of spare parts, maintenance expenses and traffic delays, during the 20-year-long lifetime of a CBI, are calculated and highlighted.*

Keywords – computer-based interlocking, reliability, maintenance, traffic delays, lifetime cost.

1. INTRODUCTION

The latest CENELEC standards for railway applications have introduced the concept of the life cycle of a CBI system. The life of a CBI 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 interlockings, 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 an interlocking including the commissioning, as a one time cost. The cost for a certain quantity of spare parts was also considered by a tender in some cases. But, the complete (maintenance) cost of an interlocking 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 an interlocking system practically determines the lifetime maintenance expenses and have a sigificant impact on

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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 of an interlocking have also not been considered as a winning criteria in any tendering process.

The purpose of this paper is to highlight the significance and value of the total exploitation expenses of an interlocking system. Maintenance expenses and traffic delay losses, during the lifetime of an interlocking, will be considered in order to show the advantages of interlocking systems with higher reliability and higher availibility. The practical example of the relevant expenses will be given using simplified calculations applied to various versions of interlocking systems, classified by different reliability features. The comparison between different CBI systems, in the aforementioned context, will be shown below and the advantages of the CBI systems with a higher reliability will be highlighted.

2. TYPICAL CBI ARCHITECTURE

The typical architecture of a CBI system is shown in Figure 1.

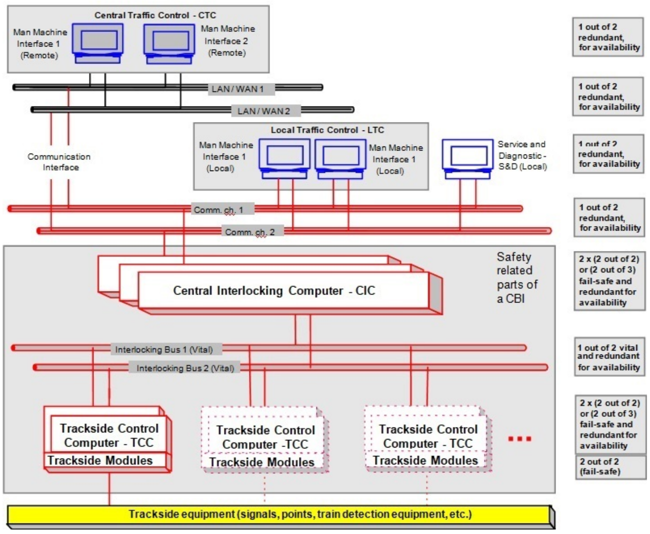

Fig.1. Typical architecture of a CBI system

The redundancy for a CBI system parts is highlighted. Practicaly all parts that are application independent are redundant. Only Trackside Modules – TMs are typically realised as a fail-safe (2oo2) system [1]. Each TM is dedicated to the control and monitoring of a particular type of trackside equipment (signals, points, train detection devices, etc.). There are generally two basic types of TMs: Signal Trackside Module – STM and Point Trackside Module – PTM. The other funcions are covered by general type of computer modules: Digital Inputs Module - DIM and Digital Outputs Module – DTM.

All modules are removable, plug in modules, that enable easier first line maintenance. Replacement of the faulty module within a redundant part does not reduce functionality, but the failure of a TM does.

3. RAMS FEATURES OF A CBI

A CBI is a scalable system. It can be used for all ranges of applications. The maximum capacity of the smallest CBI is usually up to 14 trackside elements (points and signals). The largest CBI system is mainly dependent on the technology used (speed, address and data space) and producer's concept and can contain even a 1.000 trackside elements.

CICs and TCCs realized as redundant computer systems. If one of the processor channels fails, the redundant processor channel allows that system to continue to work as a fail-safe system. As a maintenance intervention is expected in very short time (for example, 4 hours) the probability of having a second failure of CIC or TCC within that time frame, therefore leading to the interruption of CBI work is very small. Hence, during the lifetime of a CBI (usually 20 years), it is unlikely to have CBI out of order due to the failure of a complete CIC or TCC. The other parts of a CBI are duplicated for availability, and a failure in one of their channels will not affect the availability of the system as a whole. As a result, from the availability point of view, the TMs are the critical parts with the highest failure hazard connected to them.

4. RAMS CALCULATIN FOR A CBI

For the calculation of the practical reliability and availability values of a CBI system, we will use an example of a CBI containing 50 trackside elements (points and signals). In the worst case scenario we will need one TM per one trackside element. The simplified architecture of a CBI system for this application is shown on Figure 2.

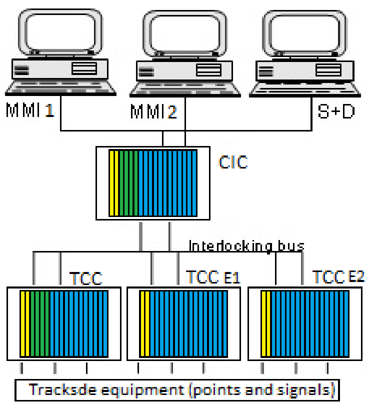

Fig.2. An example of a CBI with 50 points and signals

For this application four racks (with 18 slots) are required. One CIC and one TCC with two expansion racks are required. The CIC has a maximum of four CPU modules (for 2 x 2oo2), two BUS/COM modules and 12 TMs. The TCC has a maximum of four CPU modules (for 2 x 2oo2), 6 BUS/COM modules and 44 TMs. The total number of available TMs for the system is 56. 6 TMs will be used for I/O functions and 50 TMs will be used for points and signals. If the CIC and TCC are 2 out of 3 configurations, the number of CPUs will be six instead of eight, giving the possibility for two more TMs, but that generally depends on the producers concept and the number of slots available for TMs in each type of CBI system. Also, for some CBI systems with 2 x 2oo2 structures, the safety duplication of CPUs is realized in one CPU module, so only two slots are occupied and four more slots can be available for TMs. Here, we will consider the most restrictive case in order to demonstrate a general approach.

For the purposes of simple calculations, we will only consider the influence of 8 x CPUs, 8 x BUS/COM modules and 56 TMs on the reliability of the CBI system, as they represent the most restrictive inputs. As a TM has a simple hardware architecture in comparison to the CPU, we will make an assumption that a two channel TM has an MTBF that is equal to the MTBF of a single CPU module. The COM/BUS module is of similar hardware architecture to that of a single CPU, from MTBF point of view, so it has the same MTBF value as a CPU. In this case the number of failures and the reliability of the complete CBI system can be expressed via MTBF of TMs:

$$\boldsymbol{\lambda(CBI) = \lambda(CIC) + \lambda(TCC) + \lambda(TMs) =}$$

$$=6/MTBF(TM)+10/MTBF(TM)+ 56/MTBF(TM)=$$

$$\boldsymbol{= 72/MTBF(TM).}$$

With the increase of the number of TMs per CBI, for the larger applications, the influence of MTBF(TM) will be practicaly the most important. As a result, the simplified reliability of a CBI system can be calculated as:

MTBF(CBI) = MTBF(TM) / Number of TMs

The above expression is used for the simplified calculation of MTBF of CBI systems for various sizes of applications.

5. RAMS OF A HIGHLY RELIABLE CBI

During the last decade we have experienced new *Commercial-off-the-shelf* - **COTS** controllers, which are used for the realisation of *High Releable CBI* - **HR CBIs**. 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 TM modules (MTBF=340.667h) and they are appproved for SIL 4 railway application in accordance with CENELEC standards [4].

6. RAMS OF VAROUS VERSIONS OF CBI

During the course of 40 years of being applied, various CBI systems have been developed [3]. The MTBF for their components are generally not publicly known. During the last several years, some RA have been requesting the submission of MTBF data within the tenders. The RAMS numerical characteristics of a CBI 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 CBI systems during the tendering phase. The following analyses can serve as an example of determining which CBI system will prove to be the cheapest during its lifespan.

In the aim to compare one CBI system with other CBI systems we would have to compare their architecture and determine the MTBF values of their components. The MTBF values of TMs of various CBIs are generaly not 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]. As this information is usually known, some approximate MTBF values can be established for a certain generation of CPUs [3].

TMs reliability reflects the CPU technology that was available at the time of realization of a CBI system. As a result, the MTBF analyses of CBI systems can be based solely on the MTBF values of their trackside modules.

From the architectural point of view, only two out of three or similar systems are relevant, due to their high availability features. Hence, the MTBF characteristics of a CBI system can be determined by analogy to the here presented calculation example for a CBI. In accordance with the above mentioned considerations, various generations of CBI systems and their MTBF characteristics [2], [3], [4] that will be compared, are shown in Table 1.

Tab.1. MTBF of TMs of various CBI systems

SYSTEM VERSION (TECHNOLOGY)	MTBF of a single processor board CPU [h]	MTBF of a TFM duplicated for safety (2oo2) [h]
CBI SYSTEM A	25,000	25,000
CBI SYSTEM B	50,000	50,000
CBI SYSTEM C	100,000	100,000
CBI SYSTEM D	150,000	150,000
CBI SYSTEM E	200,000	200,000
HR CBI SYSTEM	340,667	340,667

Earlier developed processor boards based on 8-bit processors have, in general, the MTBF of about 25.000h and belong to SYSTEM A. CBI based on 16-bit CPU boards belong to SYSTEM B. Following the above described trend, SISTEM C contains 80286 CPU boards and SYSTEM D is based on 80386 CPU boards. SYSTEM E represents recent CBI systems (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.

The reliability and maintainability characteristics of the systems from Table 1, for various sizes of applications, are given in Table 2. The required spare parts and maintenance times are calculated for the lifetime of 20 years and a MTTF of 4 h.

Tab.2. MTBF, Spare TMs and Maintenance Time of the various CBI systems

No. of TMs in a CBI	30	50	100	200	300	400	500	750	1000
SYSTEM A									
MTBF(CBI) [days]	34.72	20.83	10.42	5.21	3.47	2.60	2.08	1.39	1.04
Spare TMs	211	351	702	1.403	2.104	2.806	3.507	5.260	7.013
Maint. Time [h]	844	1.404	2.808	5.612	8.416	11.244	14.028	21.040	28.052
SYSTEM B									
MTBF(CBI) [days]	69.44	41.67	20.83	10.42	6.94	5.21	4.17	2.78	2.08
Spare TMs	106	176	351	702	1.052	1.403	1.754	2.630	3.507
Maint. Time [h]	424	704	1.404	2.808	4.208	5.612	7.016	10.520	14.028
SYSTEM C									
MTBF(CBI) [days]	138.89	83.33	41.67	20.83	13.89	10.42	8.33	5.56	4.17
Spare TMs	53	88	176	351	526	702	877	1.315	1.754
Maint. Time [h]	212	352	704	1.404	2.104	2.808	3.508	5.260	7.016
SYSTEM D									
MTBF(CBI) [days]	208.33	125.00	62.50	31.25	20.83	15.63	12.50	8.33	6.25
Spare TMs	36	59	117	234	351	468	585	877	1.169
Maint. Time [h]	144	236	468	936	1.404	1.872	2.340	3.508	4.676
SYSTEM E									
MTBF(CBI) [days]	277.78	166.67	82.33	41.67	27.78	20.83	16.67	11.11	8.33
Spare TMs	27	44	88	176	263	351	439	658	877
Maint. Time [h]	108	176	352	704	1.052	1.404	1.756	2.632	3.508
HR CBI									
MTBF(CBI) [days]	473.15	283.89	141.94	70.97	47.31	35.49	28.39	18.93	14.19
Spare TMs	16	26	52	103	155	206	258	386	515
Maint. Time [h]	64	104	208	412	620	824	1.032	1.544	2.060

With the goal of estimating the value of the spare parts and maintenance time in EUR, we can assume that the TMs of all analyzed systems have the same price of EUR 5.000 and that the maintenance hour has the same price of EUR 250 in all countries.

The duration of traffic delays, during the lifetime of an interlocking, is proportional to the number of faults and MTTF. Failures of TMs have different influences on the availability of the system. The most critical TMs are those in control of elements on main lines and passing stations tracks. The accurate analyses of the elements, which are critical if the focus is on traffic disruption, depends on the topology of an interlocking and the operational constrains. Therefore, for the further analyses we can assume that only 20% of failed TMs will create traffic delays.

Tab.3. The cumulative advantages of HR CBI against CBI systems: A, B, C, D and E expressed in EUR

No. of TMs in a CBI	30	50	100	200	300	400	500	750	1000
SYSTEM A									
Total CBI [EUR*1.000]	2.532	4.212	8.424	16.836	25.248	33.672	42.084	63.120	84.156
SYSTEM B									
Total CBI [EUR*1.000]	1.272	2.112	4.212	8.424	12.624	16.836	21.048	31.560	42.084
SYSTEM C									
Total CBI [EUR*1.000]	636	1.056	2.112	4.212	6.312	8.424	10.524	15.780	21.048
SYSTEM D									
Total CBI [EUR*1.000]	432	708	1.404	2.808	4.212	5.616	7.020	10.524	14.028
SYSTEM E									
Total CBI [EUR*1.000]	324	528	1.056	2.112	3.156	4.212	5.268	7.896	10.524
HR CBI									
Total CBI [EUR*1.000]	192	312	624	1.236	1.860	2.472	3.096	4.632	6.180

We can also assume that the total duration of traffic delays will be ½ of the maintenance time required to clear the fault of the TMs that can create traffic delays in the first place. This way, the total traffic delay time will be 10% of the total maintenance time for the lifetime of an interlocking. 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, that inlude spare parts, maintenance time and the traffic delay expenses for each version of CBI is presented in Table 3.

7. CONCLUSIONS

The total innitial investment cost for a CBI was estimated in the past as the number of trackside elemets (point and signals) multiplied by EUR 50.000,00. Within our examples, we are looking at the range of 1.5 to 50 million EUR per a CBI, depending on its size. It is visible that the lifetime cost of a CBI represents a significant amount in comparison to an equivalent initial investment cost. Also, for older generations of CBI systems it is visible that the lifetime cost of a CBI can be comparable with the innitial investment cost. The consideration above justifies a need to include the reliability characteristics of a CBI system in the tenders in order to select the best bidder.

The advantages of the HR CBI system can, also, be expressed per one trackside element or TM (from about EUR 4.400 for SYSTEM E to about EUR 78.000 for SYSTEM A). Therefore, the advantage of the HR CBI system against analysed systems can be simply calculated for any number of trackside elements (TMs).

The analyses presented in this paper can be used as a guide to determine the real expenses of an interlocking 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 then 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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APPROVAL OF COMPUTER BASED INTERLOCKINGS AND PLACE OF CONVENTIONAL SAFETY ANALYSES

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Abstract *–This paper deals with the differences in approval processes between Computer-Based Interlocking - CBI systems in accordance with CENELEC railway standards and the conventional safety analyses that was imminent for the electro-Relay Interlocking - RI systems. From the early days of railways, the inherent fail-safe concept has been used. The concept is based on the use of components with well-established failure modes and a limited number of failures per component. The fail-safe design allows a safe state of the system to remain in case of failure of one of its components. The safety of this conventional concept, imminent to relay systems, can be proven by the classic and widespread adopted safety analysis, which analyses all failures and proves that a single failure cannot cause unsafe conditions. The safety Integrity Level - SIL of CBIs in accordance with CENELEC railway standards, which is mainly based on the probability approach, is introduced as a safety mesure of a CBI system. The safety integrity is the likelihood of a safety-related system satisfactorily performing the required safety functions under all the stated conditions within a predefined period of time. The aproval process of a CBI, prerformed by a certification body, ends with the generic approval of a CBI, while the application specific approval is left to the Railway Authority - RA. This includes the use of the country and project specific trackside equipment, cable network and interfaces, specific signalling rules and general functionality for a particular RA. This application specific approval is usually underestimated and could leave room for jeopardising the safety of a CBI system. The purpose of this paper is to show that a conventional safety analyses is inevitable and that it should not be avoided in the approval process of a CBI system for the particular application, especially for a new country of application.*

Keywords – computer-based interlocking, safety integrity level, relay interlocking, safety analyses.

1. INTRODUCTION

The latest CENELEC safety related standards for railways [1], [2], [3] and [4] represent an integration of the former European international and national standards. The scope of CENELEC safety related standards for a railway system is shown below.

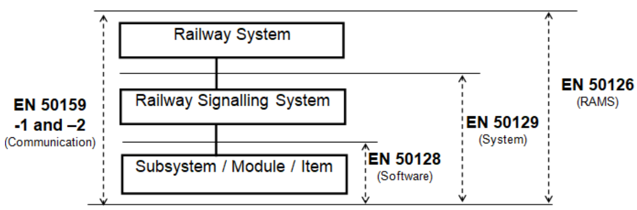

Fig.1. CENELEC railway standards

The EN 50126 standard is applicable: to the specification and demonstration of RAMS for all railway applications, from complete railway lines to major systems within a railway line, and to individual and combined sub-systems and components, including those containing software. It applies to new systems and to new systems integrated into existing systems, which have been in operation since a time prior to the creation of this standard, but it is not generally applicable to other aspects of the existing systems.

It is important to notice that this standard does not define: RAMS targets, quantities, requirements or solutions for specific railway applications, requirements for ensuring traffic security, rules or processes pertaining to the certification of railway products against the requirements of this standard, nor an approval process by the safety regulatory authority.

2. DETERMINING SAFETY

2.1. Safety analyses

From the early days of railways, the inherent fail-safe concept has been used. The concept is based on the use of components with well-established failure

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modes and a limited number of failures per component. The fail-safe design ensures that a safe state of the RI system remains in case of failure of one of its components. The main characteristics of the fail-safety design are single channel decesion flow and system resistance to a single fault. This means that a single failure cannot cause unsafe conditions. The proof of safety of this concept, known as **safety analysis**, is based on comprehensive testing of all possible failures of an RI that is performed by experienced railway signalling engineers. Numerical quantification of the safety of an RI system, expressed as *Mean Time Between Unsafe Failure* - MTBUF, is 100 years (~876.600 h) as defined by the ORE UIC.

2.2. RAMS concept of CENELEC standards

The concept explained above has limited applicability to the development and application of CBI systems. The exponential growth in the number of failure combinations when using computers makes it so that a deterministic approach is, generally, not practicable. With such complex failure combinations, the probabilistic approach can be used more effectively. This approach is supported by the **RAMS concept** of CENELEC railway standards. This concept is based on a broad risk-management approach to the safety, but it is also consistent with the fail-safe concept, well estabilished with railway engineers. A first fault (single fault) which could be hazardous shall be detected and handled in a way that entering a potentially unsafe state is prevented (negation of the failure) in a time sufficiently short to ensure that the risk of a second failure (or further) occuring during the detection+negation time is smaller than the specified probabilistic target (SIL).

2.3. Safety integrity levels

CENELEC standards have introduced the concepts of **safety integrity levels**. The safety integrity is the likelihood of a safety-related system satisfactorily performing the required safety functions under all the stated conditions within a stated period of time.

The standards define four safety integrity levels, from level “4” (very high) down to level “1” (low).

2.4. Safety case

The **safety case** sets out the safety justification for the system. It describes the project management, design and assesment techniques used in the development of the system. The purpose of safety case is not to prove that the system in question is safe – such proof is a theoretical impossibility since no system is absolutely safe. The safety case does, however, provide evidence that the risks associated with the system have been carefully considered and that steps have been taken to deal with them appropriately.

The Safety Case requires an extensive amount of documentary evidence confirming the safety of a system. That documentation is reviewed by a certification authority to confirm the safety level of a CBI. It is important to highlight that following the CENELEC standards does not guarantee that the resulting system will be fail-safe, but it allows the fail-safety of the system to be demonstrated and assessed.

2.5. System lifecycle

The **system lifecycle** is a sequence of phases, each containing a task, covering the total life of a system from the initial concept through to decommissioning and disposal. The lifecycle provides a structure for planning, managing, controlling and monitoring all aspects of a system, including RAMS, as the system progresses through the phases, in order to deliver the right product at the right price within the agreed time scales. The lifecycle concept is fundamental to the successful implementation of CENELEC standards.

3. SAFETY ARCHITECTURES

The availability of CBI systems is based on the redundancy and fault detection. The complexity and unpredictability of the failure modes of electronic components is covered by isolating the faulty module, giving the CBI system a similar level of fail-safety as the level that is present within an equivalent RI system.

3.1. Duplication for safety - "2oo2" system

The basic **safety concept** of CBIs is based on a composite fail-safety that uses hardware **duplication for safety**, known as **"2oo2" - two out of two**. This configuration is in use for numerous safety systems and it has been proven effective throughout 40 years of being put into practice [5].

For modern CBIs, the two out of two configuration is used for realization of all element-controlling modules (for signals, points, blocks, interfaces, etc.).

3.2. High availability – "2oo3"system

The duplication for safety resolves the problem of fail-safety, but reduces reliability (about two times) due to use of two units for the same function. As a consequence of decreased reliability, the availability of the functional unit and the system is also reduced. The impact on the system availability will depend on the importance of the faulty unit on the functionality of the system. But, in general, if a part of the safety system is not functional it leaves room for potential traffic endangerment. A railway operating without a fail-safe CBI system has to work under emergency procedures and is more prone to human errors.

To increase the availability of CBI systems, hardware **redundancy for availability**, known as **"2oo3" - two out of three** configuration is introduced. Such a system is available as long as two out of three units remain operational and in full agreement. Therefore, this configuration is also **fault tolerant**. On the other hand, this system is safe provided that a potentially unsafe failure is detected before a further failure occurs. The further failure, in this situation, would render both the first failure and itself undetectable. The probability of this event depends upon the units/module failure rate and mean time to detection and repair of a fault.

A similar redundancy configuration is known as **"2 x 2oo2" - two times two out of two**. This configuration has a slight disadvantage against previous one, from the MTBF point of view, due to the use of four processor modules instead of three.

The redundant configurations are in use for the realisation of *Central Interlocking Computer* - **CIC**, which contains a complete logic of a CBI and for *Element Control Computers* - **ECC**, which are used for a larger group of outside elements, or for the availability critical sub-systems, like Axle Counters.

4. SAFETY COMPLIANCE

4.1. SIL4 compliance

The appropriate SIL should be determined by a RA on the basses of the appropriate risk assesment for a particular CBI application. But, in the practice, due to lack of knowladge and resurses, railway administrations usualy require the highest SIL (to be on safe side). As a result, for a CBI system is generally required to comply with SIL4.

5. IMPLEMENTATION LIFE-CYCLE

The detailed breakdown of all of the project realisation phases of the typical railway project lifecycle, as it is for a CBI, is given in the Table 1.

Tab.1. Example of system life-cycle (from EN50126)

	Customer/ Operator	Approval Authority	(Main) Contractor	Sub-Contractor	Suppliers
Concept Phase	X				
System Definition & Application Conditions	X				
Risk Analysis	X		X		
System Requirements	X	(X)			
Apportionment of System Requirements	(X)		X		
Design and Implementation			X	(X)	
Manufacture			X	X	X
Installation			X	(X)	
System Validation	X	X	X	(X)	
System acceptance	X	X			
Operation and Maintenance	X		(X)	(X)	
Performance Monitoring	X		(X)	(X)	
Modification and Retrofit	X		X	X	
De-commissioning and Disposal	X		(X)		

X full responsibility and participation

(X) specific responsibility and/or partial participation (e.g. on sub-contract or on standby basis)

The responsibilities for each step, depending on the contractual and legal relationship, are defined and agreed upon between the parties involved. The table gives an example of the responsibilities within the typical arrangement.

6. APPROVAL PROCESS

Generally, whether the system meets the safety and other requirements of the customer can be proven only by comparison of the entire customer requirements (System Requirements Specification) and the whole interlocking system (Controlling portion of CBI, MMI, field elements, communications, software, etc.). Parts of the system, which are applicable for all projects within one RA, can be approved through the first project (type approval for example), but application specific parts of the system have to be approved for each individual project. During the approval process for the first project in a new country, the parts of the system that are not project specific, and that have already been approved by other RA could be accepted by cross acceptance.

For the implementation of a CBI for a new RA, CENEEC standard recognise three approval phases, which are considerd in further detail below.

6.1. Approval of generic product

This approval phase contains the approval of the basic system as a generic product. A basic CBI system contains a generally applicable hardware and software structure, which is independent of the particular application and which can be used for various railway applications. Proof of the safety and functionallity of a CBI system on the basic level is focused on the controlling systems' safety and availability features, system software, general structure of the software for the user, internal vital communication, general functionality of I/O modules and other properties of a CBI that are of general nature. In the past, computer controllers were approved only up to SIL3, so the approval of basic CBI systems for SIL4 was carried out through its first application in the field together with a type approval of the CBI for the specific application.

Nowadays there are *Commercial-off-the-shelf* - **COTS** controllers, which are used for the realisation of CBI systems [6]. They have a very high reliability level and they are appproved for SIL 4 railway application in accordance with CENELEC standards. Hence, they can be used as CBIs that are approved on the basic level. In addition, COTS controllers are comprised of standard components and can therefore be produced, sold, and operated at a significantly lower cost.

6.2. Approval of generic application

In this approval phase the ***generic application system*** for a class of applications, i.e. for the railway safety systems in general, is considered. This phase can represent the application of a generic system for various applications: interlocking, level crossings, axle counters, etc, for a particular RA (specific hardware and software modules). The result of this approval phase is a country/RA specific system. Only limited alterations to the hardware are expected. Specific signalling rules and general functionality for a particular RA could be integrated in this phase (geographical application software modules for a particular RA and interfaces for the specific outside equipment). The generic application system shell be approved once for a RA. This approval should be done by the client/RA itself or by the approval authority representative that is nominated by the RA.

6.3. Approval of specific application

This approval phase is related to the approval of the ***specific application system*** (project specific application parameters within the RA/country, for example an interlocking system for a railway station). This phase of the approval has to be done for every individual project with specific outside elements, cable networks, interfaces with neighbouring systems, environmental conditions, etc. It is important to notice that this phase will not have a negative impact on the general functionality and safety of the basic system and that requires a correct and safe integration of the project specific components. This approval is usually under the competence of a RA, but could also be dedicated to the RA representative.

This phase of the safety-related approvals of CBIs requires practically the same safety checking activities as those required for the old RIs and it is ideal for the application of the conventional safety analyses. In practice, this opportunity to use the aforementioned security analyses is often overlooked. The approval certificates for SIL4 of a generic product are usually considered as sufficient proof of safety for the specific application. This type of consideration could potentially jeopardize the safety of the application. An additional reference of use of that generic product in another country (other RA) that is sometimes required by the RA (cross acceptance) can not guarantee the safety of the specific application. Therefore, from our point of view, the safety analyses of the new CBI system for the first specific application in a new country shall be mandatory.

6.4. Independent safety assessment

Before the safety approval can take place, an independent safety assessment of the system/sub-system/equipment and its safety case shall be carried out, to provide additional assurance that the necessary level of safety has been achieved. The safety assessment report should explain the activities carried out by the safety assessor to determine how the system, sub-system or item of equipment (hardware and software) has been designed to meet its specified requirements. The depth of the safety assessment, and the degree of independence that are applied, are based on the targeted safety integrity level. For SIL 4, it is required that the safety assessor works for a separate company from the one that has produced the system.

Details of the safety assessment are planned and should be in agreement with the RA as part of the safety plan for the project.

6.5. The responsibilities of railway authorities

The development lifecycle of a CBI system requires significant involvement of the RA, especially for the approval of generic and specific application, through participation in the FAT and SAT (commissioning).

7. CONCLUSION

The aproval process of a CBI, prerformed by a certification body ends with the generic approval of a CBI, while the application specific approval is left to the RA. This includes the use of the country and project specific trackside equipment, cable network and interfaces, specific signalling rules and general functionality for a particular RA. This application specific approval is often underestimated and could leave room for jeopardising the safety of a CBI system. Therefore, in our opinion, the safety analyses is inevitable and should be applied in the approval process of a CBI system for the particular application, especially for the first ever application of the CBI in a new country. Also, it should be used for all applications where interfaces between CBI system and RIs exist.

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PRIORITISATION OF LEVEL CROSSINGS BASED ON RISK ANALYSIS IN THE WESTERN BALKANS

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Abstract *– Rail safety is recognised as the most important parameter in rail traffic. There are a lot of areas which can impact rail safety. One of the most sensitive points are the Level Crossings (LCs). These are points where collision between two inland modes of transport can occur.*

In an ideal situation, the best solution for the risk of collision to be eliminated is denivelation. However, just one small number of LCs have underpasses or overpasses. It means the rest of the LCs at the same level require more attention in terms of road and rail safety. The proper legislation is a crucial part of keeping a good level of safety but not sufficient. Other factors such as the LCs equipment, their operational condition and maintenance, the respect of the road signalisation by road users, marking of LCs with proper road signalisation, the triangle of visibility, and density of road traffic can affect the safety of LCs.

The ultimate goal of the Transport Community Secretariat is that there should be no more death or seriously injured because of road accidents on railway crossings! The Transport Community has a mission to help governments in the region to make the roads safer for everybody. Therefore, Transport Community Secretariat prepared this analysis to prioritise the LCs for their future improvement based on the risk they create, and like that those risks to be eliminated or decreased.

Keywords – Level Crossings; Prioritisation, Safety Improvement, Risk Analysis.

1. INTRODUCTION

Transport Community Permanent Secretariat (TCPS) is one of the pillars of the Transport Community. Within the structure, there are established Technical Committees per each mode of transport. One of them is Technical Committee on Railway. This body consists of representatives of the regional partners, EU members and DG MOVE as well as ERA, Shift2RAIL and other institutions in the role of observer.

During the sixth TC on Railway in November 2020 and the seventh in February 2021 all regional partners decided that safety improvement on the level crossings (LCs) is high ranking priority for all of them.

The main objective of this project is the improvement of the safety on LCs. LCs are a common safety issue for both rail and road traffic, and one of the most sensitive issues in land transportation.

The main purpose of this project is to increase safety on level crossings and the concrete outcome should be mapping the most critical LCs in the region.

The project, among other activities, comprises: (i) an inventory/mapping of the level crossings, (ii) a prioritisation exercise based on a risk analysis (including traffic and accident statistics) and (iii) preparation of technical parts of Tender Documentation (TD) likely for design and build approach according to the selected Contract Conditions (e.g., FIDIC).

The inventory/mapping and preparation of the relevant parts of TD is done according to the relevance of the locations of the LCs on the network, i.e., LCs on Core, on Comprehensive and on other lines. Needs for further division (e.g., grouping along certain lines and/or per geographical locations) are also assessed.

In summary, it is expected to achieve the following:

1. To provide, in close cooperation with the regional partners, an overview (so-called "mapping phase") of the LCs on the entire network (divided per the relevance of the lines, i.e. Core, Comprehensive and other lines) of the regional partners;
2. Based on a set of the comprehensive and available information collected during the "mapping phase", to prioritise the LCs according to their grade of safety (so-called "prioritisation phase"); and
3. Based on the results of the "prioritisation phase" to identify both the most critical / dangerous LCs for safety improvement measures and the feasible scope of such potential measures for urgent

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implementation.

2. LEVEL OF PROTECTION ON THE LEVEL CROSSINGS

According to the EU legal classification (a reference to Directive (EU) 2016/798 on railway safety from 11 May 2016), LCs are divided into “Active” and “Passive” (where “Passive” are those where roads cross the railway without any form of warning system or protection activated when it is unsafe for the user to use the crossing, whereas “Active” are those where the crossing users are protected from or warned of the approaching train by the devices activated when it is unsafe for the user to traverse the crossing).

In EU MS, 45% of LCs are “Passive”, i.e. 55% “Active”, while the related averages in the WB6 are much worse, i.e. in favour of the less safe “Passive” LCs. (24% of “Active” and 76% of “Passive).

3. ACCIDENTS ON THE LEVEL CROSSINGS IN THE WESTERN BALKAN

Accidents are something that is a consequence of traffic (unfortunately) but the numbers of accidents could be lower if all stakeholders work together on common solutions.

However, the most compelling insight from the above-aggregated statistics for the entire WB Region, is that **61%** of all accidents on the LCs have **fatalities or severe injuries** as their direct consequences.

Tab. 1. Number of accidents on LCs, fatalities and severe injuries in the entire WB6 Region for the period 2013-2021

Item	Number
Accidents on Level Crossings	750
Fatalities	116
Injuries	347

Indeed, the LCs are the riskiest points for the railway system and with the greatest apprehension for the Infrastructure Managers. Despite that, in some cases, there are too many accidents at level crossings. The reasons for it are the following:

- Insufficient level of protection.
- Lack of knowledge to recognise the problem and lack of reliable data regarding causes and costs.
- Ineffective risk assessment and management.
- Poor safety culture of road users (car drivers).

According to the latest research, the reasons for the Level Crossing accident are a violation of the rules on the Level Crossings and not stopping at the appropriate signal. This is the main reason for 67% of the cases. This figure gives the right to think that the Public Awareness of this issue is at a low level and the results of it and the costs are tremendous. For example, almost 300 people die annually in LC accidents (EU-28), causing economic damage of €1 billion.

The reasons behind the decision of the drivers and pedestrians not to follow the rules are different and are related to different areas from lack of understanding of the rail system to hazardous behaviour.

4. OPERATIONAL OVERVIEW OF THE LCS ON THE WESTERN BALKAN

4.1. Albania

With a valid permit, there are 104 level crossings on the main Albanian railway network. (There are 132 without permission and there is no data about signalling installed).

Out of 104 with a valid permit, 77 LCs are passive, which have only road signs, and 27 are active which have a mechanical protection system with metal barriers lowered when the train crosses.

As Albania has a very ambitious investment cycle for the coming years, the majority of the level crossings on the main lines shall be covered with appropriate projects.

Therefore, taking into account that almost all lines in Albania are covered with projects (in a different phase of preparation or implementation) and considering that only a very limited part of the network is used for operations this exercise will not take into account any level crossings which are already part of any other investments.

4.2. Bosnia and Herzegovina

4.2.1. Entity of Republic of Srpska

There are 301 LCs in total. All of them are authorised. 53 are situated on the Core Network, 205 are on Comprehensive, and 96 LCs are out of Core/Comprehensive Network.

276 are on the rail lines in operation while 26 are on temporarily closed lines.

53 LCs are part of the current projects (mainly on Corridor Vc), and those will be excluded from this exercise.

A significant number of level crossings do not have a proper distance (2000 m based on Railway Law in the Republic of Srpska). In accordance with this principle from the Law, around 70 level crossings should be terminated, mainly on Corridor Vc between Samac and Doboj as well as on Route 9a between Novi Grad and Zvornik.

4.2.2. Entity of Federation of BIH

There are 195 LCs in total on the rail network of Željeznice FBIH (the FBIH Railways).

44 LCs have active protection (3 LCs are protected

by light and sound signals without half barriers, 13 LCs protected by mechanical barriers and 28 LCs protected by light and sound signals with half barriers). Other LCs (151) are equipped with passive protection.

2 LCs are part of the current projects (mainly on Corridor Vc) and will be excluded from the prioritisation.

Because of the lack of data, the only criterion that was considered in the assessment is the road category.

Also, significant number of level crossings do not have a proper distance of 2000 m based on the Railway Law in the Federation of BIH. In accordance with this principle, around 40 level crossings should be terminated, mainly on Corridor Vc between Sarajevo and Doboj as well as between Sarajevo and Mostar.

4.3. Kosovo*

There are 295 LCs in Kosovo*. 292 LCs are authorised and 3 LCs without proper permits. 201 on operational lines, and 94 are situated on temporarily closed lines.

Currently, 27 LCs have Active signalisation, and 268 LCs have Passive signalisation.

Full rehabilitation of Route 10 (from the Macedonian border towards the common crossing point with Serbia) in a total length of 152 km is the first priority for Kosovo*. This project is ongoing and its completion is estimated for 2026. However, the upgrade of the level crossings is part of the project. In total there are 141 LCs as a part of the current projects, so they are excluded from the priorities in this exercise. During the works on Route 10, 27 LCs are in the plan to be terminated.

4.4. North Macedonia

There are 305 LCs on the Macedonian rail network. 250 with a valid permit and 29 without, while for 26 the data is not available because of the temporarily closed line Bakarno Gumno – Sopotnica.

253 LCs are suited on Core/Comprehensive Network, while 70 are out of it. Also, 267 LCs are on operational lines, and 56 are situated on temporarily closed lines.

Out of 250 with a valid permit, 95 LCs have active signalling and 155 passive.

As North Macedonia started construction works on Corridor VIII, and the detailed designs are finished for the larger part of Corridor VIII, all LCs which are recognized as an integral part of these projects, are excluded from the list of priority LCs for an upgrade.

4.5. Montenegro

Montenegro is the only regional partner which has a higher percentage of active signalling on level crossings than passive. In total, there are 23 LCs – all with permits.

19 LCs have active and 4 passive protection. 10 LCs are situated on Core/Comprehensive Network, while 13 LCs are out of Core/Comprehensive Network. All 23 LCs are on operational lines.

4.6. Serbia

Serbia has the biggest number of level crossings in the region since almost half of the rail TEN-T Core Network belongs to Serbia. The total number is 2118, all with proper permits. 1648 are suited on the lines in operation, while 470 are on temporarily closed lines. 917 LCs are located on Core/Comprehensive, while 1549 is out.

Furthermore, 254 LCs are part of the current projects, they are excluded from the priorities in this exercise. In addition, Serbia signed an agreement with the World Bank for the upgrade of 150 LCs as well as an agreement with EBRD for 35 LCs.

However, Serbia has a very ambitious plan for the renewal of infrastructure, so the next projects will be implemented by 2030 and all level crossings located within these sections will be upgraded/removed.

5. PRIORITISATION METHODOLOGY

The proposed prioritisation method follows the step-by-step process described below:

Step 0 – Calculation of indexes used in the classification process

- Calculation of a combined traffic index, as multiplication between the railway traffic and road traffic at each crossing.
- Calculation of a safety index, as multiplication between the number of accidents and the severity of those accidents.
- Ranking of the type of LC protection from 1 – automatic/manual full closure to 4 – no protection.
- Ranking of the combined traffic index from 1 – values less than 5000 to 6 – values between 40000 and 100000.
- Calculation of a combined safety performance index, as multiplication between the ranking of the combined traffic, the safety index and the ranking of the protection. The high results of this index show a poor safety performance of the LC.

Step 1 – Sorting the level crossings list by a hierarchical descending classification based on the combined traffic index. The resulting short list 1 will consist in the level crossing with a high potential safety risk.

Step 2 – Sorting the level crossings list by descending classification based on the safety index. The resulting short list 2 will consist in the level crossing with a high existing safety risk.

Step 3 – Sorting the level crossings list by descending classification based on combined safety performance index. The resulting short list 3 will

* This designation is without prejudice to positions on status, and is in line with UNSCR 1244 (1999) and the ICJ Opinion on the Kosovo declaration of independence

consist in the level crossings with a poor safety performance. This list is a comprehensive one, identifying both the level crossings with potential safety risk, along with the ones having existing considerable safety risks.

Step 4 – Based on the short list 3, a classification of the level crossings is realised on various levels:

- First level of prioritization – the level crossings that are identified as common to all three sorting steps, by intersecting all 3 resulting lists, showing that the existing and potential safety risks are high regardless of the sorting method
- 2nd level of prioritization - the level crossings that are identified as common to the intersection of the Step 2 and Step 3, showing the level crossings that will maintain their exiting safety risks in the overall safety performance evaluation
- 3rd level of prioritization - the level crossings that are identified as common as common to the intersection of the Step 1 and Step 3, showing the level crossings that will maintain their potential safety risks in the overall safety performance evaluation
- 4th level of prioritization - the level crossings remaining after applying step 3 within the short list 3.

6. CONCLUSION

Investment in level crossing safety must also be balanced against other safety risks. Thus, it may not be possible because of a lack of funding to immediately achieve long-term safety improvements at all level crossings. Since such prioritisation was needed, a model was applied to evaluate the risk. Through a safety management framework of re-assessment and monitoring, we can continuously evaluate safety risks and prioritise expenditure appropriately, making sure risks are managed and public money are invested wisely. Finally, the outcome must be action, action and action, since the situation will not improve on its own.

With reference to the performed activities and findings presented in this paper, it can be concluded that the initial stage of the initiative has been completed with satisfactory results enabling the further planning. Also, the performed activities have resulted in a structured and comprehensive set of data relevant for all the level crossings on the railway network of the WB6.

Irrespectively of the (future) activities related to this specific initiative, it is suggested that the Regional Partners supplement the data with the missing information and maintain the prepared data monitoring of all future activities related to safety improvement at the level crossings. In that context, it is suggested that the updates are done on an annual basis and that particular attention is paid to the collection of information on the intensity of the road traffic at the crossings. The Permanent Secretariat, within the scope of their responsibilities, will try to agree on the reporting arrangements with the Regional Partners.

The next primary objective will be preparation of the technical specifications of the tender documents for safety improvement of the level crossings (supply and installation of new equipment) and the scope of the services for potential technical assistances for designing for de-levelling.

In parallel with the physical upgrade of the safety level of the level crossings, TC Secretariat developed and carried out a public awareness campaign.

The public awareness campaign for improving rail level crossings safety targeted a wider audience via dedicated events, broadcasters and social media, and other communication channels and with print materials, videos etc. Both measures, the physical upgrade and the campaign, are aiming to decrease the number of accidents on rail level crossings towards the "Vision Zero" deaths until 2050. For the success of the public awareness campaign, it was out of crucial importance to reach as much as possible wider audience and use all available communications channels to convey the message.

ACKNOWLEDGEMENT

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UNIVERSAL TRAIN CONTROL SYSTEM – MILE*

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Abstract *– When it comes to interoperability of Europian railways in the domain of Comand Control System, the scene seems to be fully set: the Directive of Interoperability has been adopted now for a long time, and Technical Specifications on Interoperability defining ETCS level 1/2/3 as a single protection system train have been established. The problem is that on this seemingly perfectly set stage there is too little performance, and all activities seem more like rehearsals than well-coordinated acts. The best illustration of the above impression is the fact that, of the total length of 230.123 km of railways in Europe, only 2.700 km are equipped with some ETCS level. This is only 1.17%, almost at the level of "statistical error". This paper identifies both conceptual and financial reasons for such effect. The main problem is in the concept of ETCS, which repeats the patterns of existing national train protection systems that are to be replaced. The paper presents an innovative one-part train protection system that is universally applicable to all lines, with current state of infrastrucure, and for speeds up to 160 km / h. The system is based on the optical principle of signal identification and signal markings and effectively overcomes the deficiencies of the original ETCS concept. Its application is especially effective on lines that are not equipped with protection systems at all, which for example makes up 60% of all railway lines in Serbia. The use of this system would bring traffic safety on these lines to ETCS Level 1, without any additional established investment in infrastructure.*
MILE - Multifunctional Interoperable Locomotive Equipment, invention of M. Babić.*

Keywords – Interoperability, train control, train protection, assistant driver, moving block.

1. INTRODUCTION

Interoperability is the ability of the railway system to organize and implement safe train running on routes covering several railway administrations in Europe, without the need to change the composition of rolling stock and train. In order to achieve this ability, many parameters of the railway system must be harmonized, from physical and organizational to legal. DIRECTIVE (EU) 2016/797 which inherits and consolidates Directives 96/48 / EC, 2001/16 / EC, 2008/57 / EU and more other documents, identifies several subsystems that are divided into structural and functional areas that need to be harmonized with the Technical Specifications of Interoperability - TSI. The Control Command and Signaling TSI defines a single European ETCS system that should ensure interoperability in train protection and management. Simply put, all railways in Europe should abandon existing national train protection systems (there are more than twenty of them), and install one of three ETCS levels, thus meeting the interoperability requirement of train protection subsystems. ETCS started more than ambitiously, but thirty years later, in operational use on the European railway network, it is found in "only in traces", and now there are three basic specifications (baseline1/2/3). The problem is that track equipped only with ETCS system is only available to vehicles with ETCS equipment. This leads to the practice that infrastructure owners, as a rule, keep the existing national train protection system in parallel with the newly installed ETCS, so the railway is equipped with at least two train protection systems. It is obvious that the transition to the ETCS system of any level requires exceptional work, organizational ETCS and financial efforts, both for the owner of the infrastructure and for transporters. For now, there are no solutions within the ETCS specifications that will resolve those contradictions. The path to interoperability is not easy - the question

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is whether this situation can be changed and in what way. The following is a proposed solution based on the Universal Train Control Device, which, without limitation, can be applied for speeds of up to 160 km on existing lines.

2. MILE - UNIVERSAL TRAIN CONTROL SYSTEM

The technical problem to be solved by the universal system is how to implement a universal system that will allow the driver to drive vehicles / trains safely, and in accordance with the signal, on any railway line in the current state, with speeds up to 160 km/h in any driving conditions. This task can only be solved with a one-piece locomotive train control system, which operates independently, without rail part of the system (balises, loops…). A completely new method of acquiring the signal concept, from the signal in front of the train, into the train management system should be implemented.

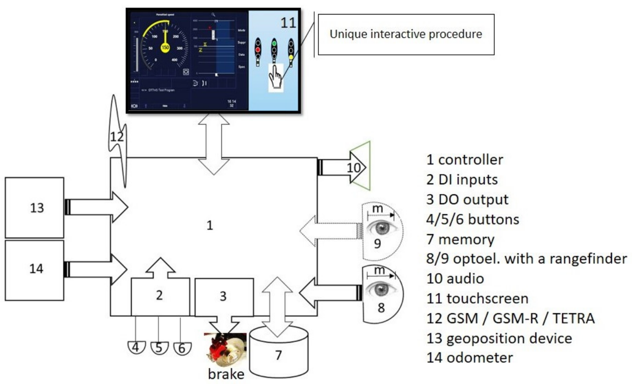

Fig.1. Universal system MILE

Figure 1 shows the universal system, which substantially changes the principle of operation of existing TCS / TPS systems - it replaces communication method of identifying the signal with the optical method. Universal functionality of the device is based on the use of day/night optoelectronic device ("computer vision") with rangefinder, and device for geographical positioning of objects on the ground in real time. Also knowledge of signaling along the track, prescribed train driver activity and interactive train drivers communication procedure with "man-machine interface". The universal system works as follows: after the driver enters the train data and starts the program, the central unit retrieves all data on objects, signals and signal marks on the train route from the infrastructure database, which is in permanent memory. The data contain geographical positions of relevant facilities, bridges, tunnels, stations, stops, road crossings, etc. as well as positions and data on fixed signals, and signal markings on the route. The infrastructure database also contains data on maximum speeds, breakpoints, sections of easy driving and limited speed, maximum speed in the direction and turning at stations, data on the zone of visibility of objects and the meaning of signals and signal signs. There are predefined graphic representations of objects as well as graphic representations for railway signalization identical to the ones in the Signal Rulebook.

The infrastructure database can also be located in the central infrastructure base outside of the vehicle, in which case the central unit retrieves data using a radio communication device. Infrastructure data should be up to date. The updating of the infrastructure base, which is located in the permanent memory, is performed by the driver, manually via the touch screen or by downloading the content from the portable memory medium, after receiving the order from the authorized operational personnel. If the infrastructure database is centralized, updating the data is an independent process, separate from the driver's job, and must be performed in real time, ie. the change should be made immediately after it has occurred. The interactive dialogue man-machine, which is used to reliably identify the conditions for safe train driving, relies on the driver's obligation to harmonize train driving with the signals he sees on the train route. A system that has a precise positional awareness of the track, at predefined characteristic points, signals, signal marks, initiates an interactive safety procedure for operating the device. By conducting a predefined interactive dialogue, the system receives "real time" data on signaling conditions for the realization of driving, which is carried out through the dialogue machine - man: announcement / request - response / choice - request for confirmation of choice - confirmation of choice. Figure 2 illustrates the interactive dialogue, which is conducted on the APB signal, which can show three different signal signs green / yellow / red, in a situation where the signal in front of the train shows green.

In this way, what the system "knows" about the track is harmonized with what the driver sees. Train is allowed to run only if the system and the driver agree, and the signalization on the track does not prohibit further driving. In the event that the procedure is not followed or the driver fails to follow the signaling, the system generates a warning and starts forced braking, when necessary. After the procedure, the system controls the driver's actions in accordance with the meaning of the signal sign taken in the procedure, and according to the requirements prescribed in the Signal Regulations, because it has all the necessary train parameters and tracks for dynamic speed control until the next signal. At the same time, by performing this procedure, the driver informs the device that he is awake, situationally aware and concentrated on the task of train management. Thus, the implementation of this procedure also serves as a replacement for

Vigilance device.

If the system is equipped with an optoelectronic device day / night with software for object recognition ("Computer vision") the procedure can be simplified reduced only to the confirmation of the signal concept by the driver, which is detected by the device. The system is in constant interaction with the driver feedback - "the system controls the driver, the driver controls the system". It can be said that the system has an inherent "fail safe" property: as long as the system announces the elements of the infrastructure, which the driver sees and confirms, the main functions of the system work correctly - the system has performed correct positioning, the optoelectronic device correctly recognizes the infrastructure element in front of the train, the transaction over the base is performed correctly. If any procedure in this chain of cross-checks is absent, it indicates a potentially dangerous situation, and the system will warn the driver. And if the expected reaction fails, system will not allow further driving. In order for the system to be completely safe in case of failure, it is still necessary to perform a two-channel calculation of speed recommendations in relation to the train location, and the recommendation is shown to the driver only if the result of processing in both channels is the same. All events in the system, whether automatic or driver action / system response to action, are stored in non-volatile memory. In this way, by recording the event, the system integrates the function of data-recorder and the function of monitoring vigilance. Vigilance control has a new additional feature - checks "awareness" (driver attention / task focus).

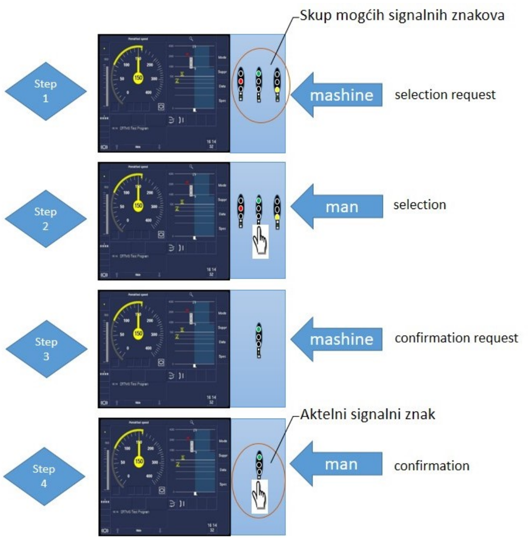

Fig.2. Interactive dialogue

The device is universal according to several criteria: it replaces all existing devices on the vehicle (AutoStop, Speedometer, Data-recorder, Vigilance), performs the function of driver's assistant, and is universally applicable on all lines in its current state, regardless of the applied signaling system. Finally, perhaps most importantly, the device provides train protection at the level of ETCS level 1 system, which is incomparably more than the protection provided by the INDUSI in the configuration used on the main lines of "Serbian Railways". The following is a comparative table of the essential features of the ETCS-1 / UNI TCS-MILE / AS INDUSI protection system, which most effectively depicts the similarities and differences in the characteristics of the train protection system.

Tab. 1. Comparision ETCS-1, MILE, INDUSI

No	ETCS-1	MILE	IND USI
Constru-ction	Two-piece (train / rail)	One-piece (train)	Two-piece (train / rail)
Applica-bility	Limited to equipped lines	Universal	Limited to equipped lines
Access control	YES	YES	NO
Vigilance control	separate	integrated	separate
Driver's navigation	YES	YES	NO
Continuous speed control	YES	YES	NO
Control	Spot	Quasi-continuous	Spot
Event registration	YES	YES	YES
Observing obstacles in front of the train	NO	YES	NO
“Moving block”	NO	YES	NO
Video registration of the ride	NO	YES	NO

3. TRAIN PROTECTION SYSTEMS AT SERBIAN RAILWAYS

At Serbian railways the inductive train protection system AS (Indusi) is applied. It is installed on the main routes and on the side routes no train protection system is installed. The system in some cases is not complete, it is without 500 Hz balises and speed control devices, therefore the system does not cover speed limits and speed breaks, slow rides, reduced speeds or output station signals (except for output signals on through tracks). AS does not have capabilities to assist locomotive driver, neither in terms of announcing objects on the track, nor in terms of constant dynamic speed control. It protects the train from rude driver errors: the passage of a signal that does not allow driving, and exceeding the speed at a predefined control point in the pre-set operating mode.

Modernization works on the line Belgrade-N. Sad-Subotica are underway. ETCS level 2 is applied on the track, which is in accordance with the EU Railway Interoperability Directive. The problem is that ETCS is still a two-part system, consisting of a track and locomotive subsystem. But there is a small number of towing vehicles with ETCS system compared to vehicles equipped with a national AS protection system. Although ETCS level 2 does not require track signaling, it is still retained and inter-station distances are equipped with the APB system. This situation is not a special case in Serbia, it is a rule wherever ETCS is introduced, especially on conventional or mixed traffic lines.

4. IMPROVING TRAIN PROTECTION SYSTEMS OF ŽS RAILWAY LINES

All indications are that trains running on the railway network are insufficiently protected: most of the railways are not equipped with protection systems at all, and main lines are with Indusi system which are sometimes incomplete. The practice of using locomotives without AS on Indusi equipped railways and the practice of single-seat, as defined by Instruction 428, certainly does not contribute to traffic safety. Modernization of route Belgrade - Subotica will introduce a new standard in train protection, but we have to wait the effects of ETCS mode. The question now is whether there is a way to reduce or exceed the disproportion in the protection of trains on the main lines in relation to the secondary routes at a reasonable price and acceptable deadlines, and in what way? The first thing that comes to mind is the introduction of the national AS system on the side lines. This calls into question several technical and practical questions. First of all, the purpose of the Interoperability Directive is to abandon existing national systems in Europe and replace them with a single new ETCS standard. More importantly, the technical conditions for the expansion of AS systems are difficult. If AS system will be installed on the side tracks in the capacity of the existing AS on the main lines, or if it will be decided to install some of the ETCS levels, the contractor would be faced with similar problems - several different interfaces (according to the various signaling devices present on the side lines). So we believe that the only realistic and justified solution for the protection of trains on the side lines of the railway is UNI TCS - MILE / Electronic Assistant Driver. Its application would not only increase the level of train protection to the rank of ETCS-1, but would also solve the problem of two-seater trains. Application of MILE is not limited to secondary lines it works at all tracks with external signalization, so also including the Belgrade-N. Sad line.

5. CONCLUSION

The interoperability of the CCS system is clearly not solved in a way to find a technical system that adapts to the different signals of national railways. This new ETCS system, which is essentially a compilation of the existing national protection systems, will solve the problem of different signaling with a single interface of the train driver system. This method works at higher levels of the ETCS system 2/3 because the cab signaling is authoritative for train driving, and the driver is guided exclusively by the interpretation of its meaning. For ETCS level 1, in addition to the cab signaling, driver is guided by external signaling, which then assumes that he knows it and is authorized to drive the train in such conditions. The driver does not have to know the signaling he encounters while driving, he only needs to identify the signal sign icon in front of the train. The interpretation of the meaning is on the MILE system. MILE system can be fully automated: the identification of signal signs is performed without the participation of the driver and using dual optoelectronic systems with rangefinder. In this case the functionality of the system is expanded with the ability to detect obstacles on the track and possibility to have successive trains without APB devices in "moving block" driving mode. It can be said that all known train protection systems adapt the railway infrastructure to the system, but MILE system adapts to the railway infrastructure. Important difference is evident in comparation with systems that are all two-part, and MILE system is one-part, which is advantage in price and convenience for installation, also maintenance and universality of application on infrastructure in its current state. To be overcome the apparent delay in the implementation of ETCS the MILE system needs to be standardized within ETCS Level 1. The MILE system is also the most efficient way to compare the protection of trains on secondary railway lines in the fastest, simplest and cheapest way.

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XX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
RAILCON '22

TECHNICAL AND ENVIRONMENTAL ASPECTS FOR THE PURPOSE OF IMPROVING THE SAFETY LEVEL AT THE LEVEL CROSSINGS ON THE SERBIAN RAILWAYS NETWORK

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***Abstract** – Because of increased road and railway traffic capacity, intersection of road traffic lines with railway lines, i.e. level crossings, represent dangerous places with frequent irregular events. Analysis of these accidents primarily identifies human factor as the primary cause, while other conditions such as current state of pavement, driving vehicles or equipment are often disregarded. Basic requirement for measuring the safety level at level crossings is reduction of number of irregular events. There are different ways for achieving this goal and they depend on both existing and required safety level at the level crossing. Therefore, reconstruction of the level crossing in sense of the scope and quantity of predicted works is very specific process, having in mind that disturbing both railway and road traffic shall be minimized and in the same time performances of the level crossing (construction, environmental and interlocking) shall be optimized. In this paper, level crossings on the level of "dangerous places" were treated comprehensively, first during the preparation of the technical documentation, and then during the execution of works and installation of equipment - reconstruction and raising the level of safety at level crossings.*

Keywords – level crossing, signaling-interlocking device, traffic, environmental, safety

1. INTRODUCTION

Level crossings, as very dangerous points and "black spots", require a comprehensive treatment in the preparation of technical documentation with the ultimate goal to reduce the number of emergency incidents at these points , i.e. the reduction of fatal traffic accidents and material damage caused by vehicle collisions of two completely different modes of transport.

That is the reason why every request to solve the intersection of a road with a railway line should be analyzed in detail and individually, considering wider zone, that is, the longer stretch where the road crossing exists simultaneously, from the traffic technology, civil engineering, electrical engineering and environmental protection aspects.

This paper sets out to define what is common and the most rational approach when reconstructing and increasing the safety level of each individual level crossing.

1.1. Level crossing characteristics

In order to design, plan and carry out reconstruction/maintenance works at level crossings efficiently, it is important to single out the general characteristics of level crossings:

a) category of road and railway at crossing point;
b) location of the level crossing;
c) visibility at the level crossing and intersection angle;
g) volume of the road and rail traffic in the level crossing zone;
d) the substructure and superstructure at the level crossing and the pavement of the road
f) the way of signalling and interlocking, power supply and lighting (existing and improved)
e) environmental status in the level crossing zone.

1.2. Users and their requirements

The Law on Railways of the Republic of Serbia is a legal act which clearly defins that ’’manager’’ and

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’’road manager’’ are the two most important institutions in charge of maintenance and safe traffic flow at level crossings. Other institutions that should also be metioned are the Electric Power Industry, Water Supply and Telecommunication companies because without their consent and conditions, not only the project of increasing the level of safety at level crossings, but also not a single serious investment project can be started or completed.

The mentiond group of institutions led by ’’manager’’ and ’’road manager’’ belongs to the same group of participants - a user (SMQ-System Managemenet Quality terminology) of a particular product or sevice. Their joint aim is to arrange, monitor, control and implement necessary activities in accordance with the Law and regulations, from project documentation, obtaining a building permit for the construction/reconstruction to the technical acceptance of the reconstructed level crossing.

The second group of participants of the project for increasing the safety level at level crossings is – a supplier whose activity is the preparation and implementation of the project documentation, which in its final form should satisfy the user’s preset requirements.

Each of the aforementioned participants have clearly defined goals, which, although sometimes opposed, have one thing in common– the tendency to successful implementation of the project for increasing the safety level at level crossings.

2. FACTORS AFFECTING THE PLANNING AND IMPLEMENTATION OF WORKS AT LEVEL CROSSINGS

The planning process is of crucial importance in any management system, because good planning, in addition to quality, contributes to significant savings in material and financial terms

Having in mind that the investment for increasing the safety level is significant, before deciding on the method and system of the level crossing safety, the following groups of factors should be taken into account: technical, economic and environmental.

Planning should be carried out in accordance with the Rulebook on intersection of the railway line and roadway, pedestrian or bicycle path, the place where the intersection is possible, and traffic security measures (“Official Gazette of RS” no. 89/16).

2.1. Technical group of factors

Basically, there are three groups of measures to increase traffic safety at level crossings: traffic and civil engineering, electrical engineering and other measures. Which of the mentioned measures will be applied depends on which legal regulation the particular level crossing is subject to, so it is necessary to be specified.

A specific measure to ensure the safe flow of traffic at the level crossing should be implemented in accordance with the regulations, and after the analysis of traffic density, visibility triangles, permitted speeds on the railway line and road, as well as according to the frequency of emergency events at the road crossing.

Traffic and civil engineering measures are implemented within temporary and permanent traffic signalling (road/railway), i.e. by replacing elements of the substructure and superstructure of track grids of the railway or rail track, i.e. by rehabilitation of the road pavement in the level crossing zone.

Electrical engineering measures are carried out within the framework of: power supply of the level crossing, replacement of the safety system elements, telecommunication elements, as well as the lighting method of the level crossing.

2.2. Environmental group of factors

Environmental factors which affect safety level of the level crossing is mostly determined with execution of works on the level crossing reconstruction.

The main issues during reconstruction can be oriented on: noise, dust, protection of water and soil pollution from improper material storage, management and usage, waste management and temporarily occupied areas.

Mitigation measures should be clearly defined through the Environmental management plan and implemented by the contractor and supervised by the supervision.

2.3. Economic group of factors

Economic factors which affect safety level of the level crossing are primarily determined by the real traffic importance of the level crossing (category of the railway and road, volume of the rail and road traffic at the level crossing), by the number of railway personnel needed for regular service and ongoing maintenance of the level crossing devices, as well as by the difference between investment values of the existing and new construction arrangement and safety system.

Before making the final decision on how to increase the safety level, in planning phase, the recommendation for beneficiary (namely the institutions in charge: the Serbian Railways and relevant enterprises for road maintenance, the Electric Power Industry and utility companies) is to create a suitable mathematical model ("cost-benefit" analysis) which will include algorithms for determining the optimal safety level of the level crossing and provide a prediction of long-term maintenance costs. Based on the model, the scope of construction works and safety system would be specified.

3. IMPLEMENTATION OF ACTIVITIES TO INCREASE THE LEVEL OF SAFETY AT LEVEL CROSSINGS

Along with the project documentation, the conditions and consents obtained from the relevant authority institutions and other public enterprises whose interests overlap with the interests of the Public Enterprise Serbian Railways – increasing the level of safety at level crossings, for the further implementation of this iterative procedure, it is necessary to obtain the approval for construction (or decision on approval of works) from the Ministry of Construction, Transport and Infrastructure, based on the specified documents.

During the execution of works on the level crossing reconstruction, the method of carrying out and organization of rail traffic is regulated in cooperation with the relevant departments of the "Serbian Railways Infrastructure". Issuing permits for the commencement of works, limiting the speed of rail traffic, closing the railway line and re-opening the railway for traffic, as well as the regulations defining the behaviour at the site of work execution is responsibility of the "Serbian Railways" and it shall be coordinated with the timeline plan of the work execution.

It is also necessary to prescribe temporary traffic organization measures about which both railway personnel and railway transport users shall be adequately and timely informed.

3.1. Results of implemented activities

The decisions on reconstruction are followed by the standardized procedure which should result in the selection of the category and sub-category of the level crossing device that will be applied in the specific case, and afterwards, in the tender procedure, the selection of the specific supplier of the device. In addition to the general conditions prescribed by a law for this type of works, when defining the conditions for the selection of the level crossing safety devices, some of the special conditions should be fulfilled, in order to justify the reconstruction in technical terms:

1. the new safety system should have an increased safety level compared to the existing one
2. the new safety system should have an increased number of functions compared to the existing one
3. the use of the level crossing device should be easier, both for users and for maintenance personnel
4. the electricity consumption should be lower with the new safety system
5. closing time of the level crossing for the road traffic should be reduced etc.

3.2. Method of work execution

Works with temporary deviation

In case such a technical solution is chosen so that, during the execution of works, road traffic is diverted to a temporary deviation of the road next to the level crossing, depending on the category of the railway and the traffic volume at the level crossing (road and rail), it is necessary to consider the provision of temporary deviation with a simplified signalling and interlocking device (most often installed on the site by a competent responsible employee of the "Serbian Railways" during the execution of works).

Works with the flow of traffic

The project of the work execution with the flow of traffic is usually in the form of the Elaboration Report "Plan for marking and securing the work site in the zone of railway line and road intersection" and it is prepared not only for the works resulting from the newly proposed technical and technological solutions, but also for the needs of work execution due to the repair of railway or road, and often for historical routes.

The Elaboration Report is usually prepared based on the request of the Railway Maintenance Department of the Construction sector of the Public Enterprise "Serbian Railways" or the Directorate for Roads responsible for the road, the owner of the road.

- The Investor's request for preparation of the Elaboration Report
- Location and work sites
- The reason and purpose of the work execution
- Plan for marking and securing the work site

Appendices

- Situational plan with the site location with the surrounding road network
- Work site marking plan by stages and phases of works
- Details of marking the work site
- Information to authority organizations and institutions about changes in traffic during the works
- Specification of traffic signs and equipment by stages and phases
- Decision of the Ministry of Construction, Transport and Infrastructure authorizing the Investor to install temporary traffic signals and equipment and to change the traffic regime at the site (or in the zone).

4. CONCLUSION

Reconstruction and increasing the safety level at the level crossing is a process with a large number of input parameters (sub-processes), optimized management by which a decision can be reached unambiguously on how to increase the level of safety for each specific level crossing. By the proper development and monitoring of the process of decision-making about each individual level crossing, the result may be also a decision to cancel or to level the crossing. The creation of a single base of level crossings with previously adopted technical and technological requirements, which shall be fulfilled along with an assessment of the investment value according to the type of the equipment and works within the framework of technical factors (construction, electrical engineering and traffic) in the long term, is the way of the planned activities implementation at level crossings, including environmental criteria.

After the completion of works, each individual investment can be comparatively evaluated and possible modifications can be made for future projects.

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ACQUIRING PASSENGER TRAIN MOVEMENT INFORMATION USING CRITICAL SYSTEM'S DATA

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Abstract *– Positioning the train in time and locating it, is essential for a variety of railway services. The complex system of network environment must enable the users to get information about train movement using mobile phones or info tables in stations. This paper will elaborate an example of extracting the train movement location from critical services using a series of firewalls.*

Keywords – signaling systems, firewalls, passenger information.

1. INTRODUCTION

Information about the exact position of the train on the railway line is an important information that is used by many services. Correct positioning information is affected by certain problems and threats along the line as well as in the system. These threats could disrupt the systems and even affect the movement of the train itself. This paper deals with critical systems that manage and monitor the running of trains as well as non-critical systems that provide information to different sub-systems. With the development of technology, a number of significant devices have improved so that now advanced protection of devices is mandatory in certain applications, aiding and simplifying access control and data flow.

There are several methods for obtaining train movement data intended for non-critical systems, one of them being the server structure presented and elaborated in this paper, based on safety and security postulates of cybersecurity [1-3].

2. TRAIN MOVEMENT POSITIONING

The flow of train movement data in non-critical systems is controlled by the network infrastructure itself, various policies, access lists, credentials and even protections at the application level. Backup systems are also introduced, so if a part of the system fails, backup is automatically activated and the system can continue to provide and process information about train delays.

Data about the positioning of the train intended for non-critical system on the railway line can be obtained from several systems.

In previous period this information was entered into system by train dispatchers in the stations, and these data were intended for passinger information systems only (Fig.1a). This was the case because the older critical systems had no possibilities for extraction of this kind of data.

With the arrival of high-speed trains, any human verification of rapidly changing data becomes uncertain, which is further compromised by delays in the transmission of information to the destination. Another issue arising because of the delay in entering information is false information published on the passenger information board. Over time, there is also a reduction in staff at the stations, due to automation and new technologies, so this kind of system is no longer reliable.

Another way of defining the position of the train would be using GPS and a bar code, marking each train, which is a good solution for the most part. In some countries, such a system is in operation, but is supplemented with some other auxiliary systems. For our region, where a large number of domestic and foreign operators are expected, as well as international

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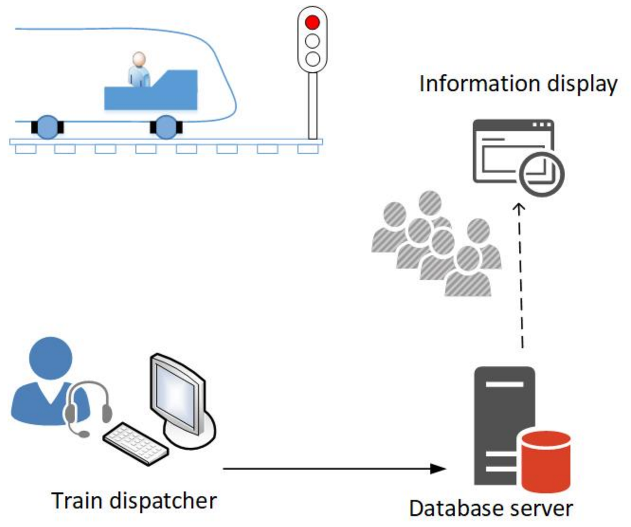
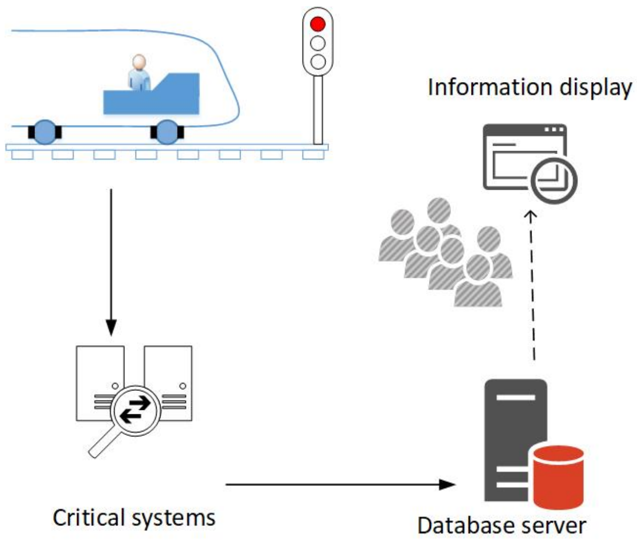
trains, these methods of defining the position of the train are not acceptable and it is necessary to resort to some new ways of obtaining data on the position of the train.



a)



b)

Fig.1. The train movement data flow: a) train movement is registered by train dispatcher and b) train movements are monitored by signaling systems, which then distribute the needed data further towards servers of non-critical applications.

The third option for data obtaining is to download information about the exact position of the train from critical systems (signaling systems). Here a problem arises because in systems where the movement of trains is directly controlled, it is necessary to avoid any errors, or the possibility of affecting the operation of some of the critical systems. In this part, it is necessary to focus on the network server environment and to define what such a system would look like, with obtaining information from critical systems, without jeopardizing the systems that manage the running of the trains. The Fig.1b depicts the flow of data in this kind of solution.

3. EXAMPLES OF SERVER STRUCTURE

The previously presented third solution has several version, based on the good practise. On of the possible versions is presented in Fig.2. The figure depicts the emphsised middle server as the means of secure and sade extraction of train movement data from critical systems.

The train movement data is critical data and have to be used regarding security and safety aspects [4-6]. Therfore, all server structures must be formed based on the top level security principles. Mentioned treaths and problems are here extended to unatuhorised entrance, and intrusions, etc. These threats must be assessed and disscussed during the desing of these systems.

One of the ways to break into servers is to make queries using default credentials, so at the server level, it is necessary to predefine default credentials. A certain exchange of information between the server and the attacker, via the TCP/IP network, would also provide such information. The next step is the positioning of the server, which would be between the two sides, critical and non-critical systems. This server is obliged to only communicate with one and the other party and to keep all data from critical systems on itself, as a copy. This move avoids direct access to critical systems. This reduces the vulnerability of critical systems. Communication between servers would be exclusively critical system-to intersystem, intersystem to non-critical system. Communication would generally be resolved through certain queries, in relation to the type of database and information that is necessary.

Protection at the network level should also be defined in design stage. For this purpose, it is necessary to define certain applicable types of firewall devices. It is possible to filter traffic on firewall devices, allowing or disallowing transmission, based on the direction, network address, MAC address, type of traffic, and the like.

Newer generation firewalls enable this and are used for protection in a large percentage of these kind of applications. It is necessary to place such a device both in the critical system and in the non-critical system as well as in the middle of the system where the central server for information exchange is located. One of the better ways of protection is the installation of unidirectional firewall devices [7-9].

These are devices that work on the same principles as a classic firewall, but with greater sensitivity and with capability to shut off transmission in only one direction. These are specialized devices that are used only for network featuring critical systems (systems through which traffic management is enabled).

The following figure (Fig3.) shows the version of complete system with positioning of both classic and unidirectional firewall devices.

Because of the simplicity, common knowledge of this system and prevously existing versions passinger information systems is chosen as the main example in this paper. System for provison of this kind of data via mobile phone could be a good but in most cases more complicated for presentation.

Apon reflection on such a system, it could be seen that subservices, intended for passengers, for example, must request information about the position of the train from the server in a non-critical system. Each sub-service requests only some of the information from the server. The server itself receives all data from the server from the middle of the network through a unidirectional firewall. There is no other way to get the information. Also, the server in the middle part only receives information from servers from critical systems through a unidirectional firewall device. The server in critical systems receives information from certain systems and stores it in the database.

The cost of such a system could be discussed but it is justified with reduction of vulnerability it promotes. It provides complete blockag of access to critical systems, from all sides, because it is not possible to easily move from one system to another, through inter-systems, and a series of firewall devices. Here a series of question arise one of them if whether such a system can become infected and become problematic. The answer is al always yes. Since the entire system is based on the TCP/IP architecture, the use of only peripheral devices can lead to a breach of the system. Laptop devices will probably be used for system maintenance. Employees use USB devices during maintenance to transfer or archive some data or information and the like. In order to detect a problem in the system and to react quickly, it is necessary to have firewall devices, on the workstations, to use agents that communicate with the firewall devices, to have a strictly defined policies on the devices so that if a problem is detected in the transmission, a DDoS attack or the like, the devices are automatically isolated. The definition of NOC i.e. Network Operation Center, will also be a must, forming a department that will monitor the state of the Ethernet network 24/7, at all levels, etc.

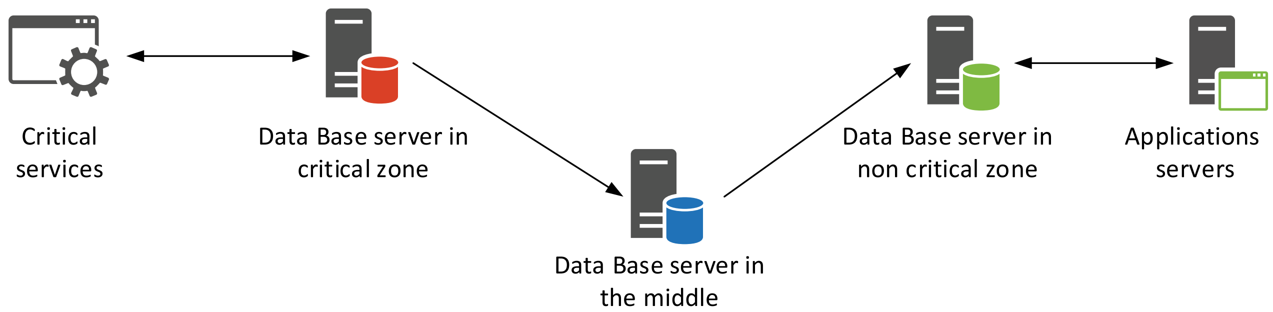


Fig.2. Version of server structure for extraction of train movement data from critical systems

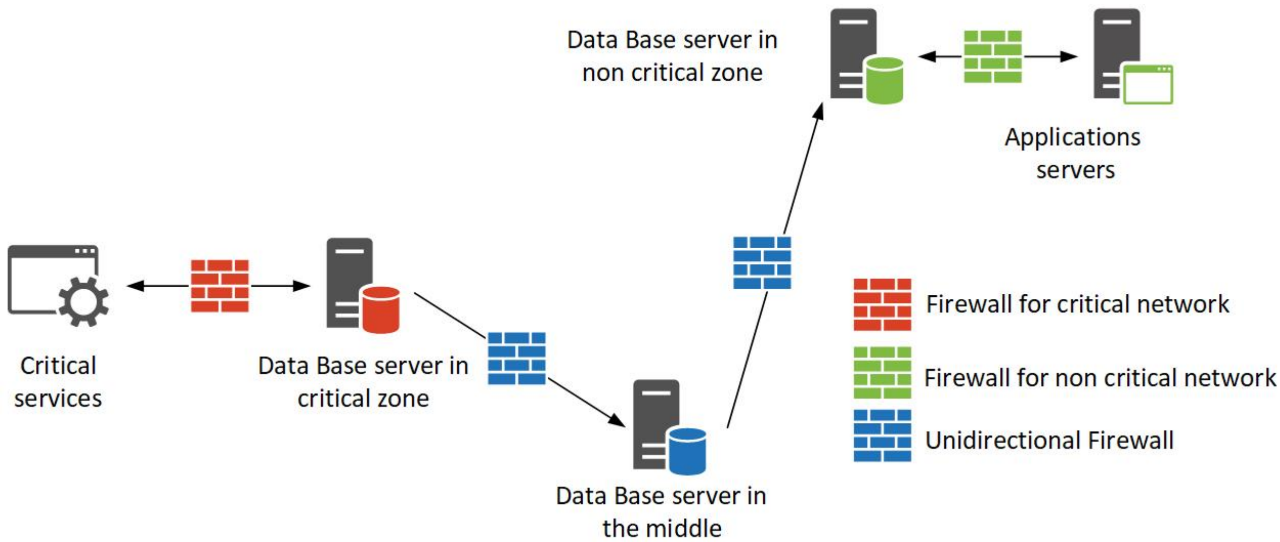


Fig.3. Version of server structure using both classic and unidirectional firewalls.

4. CONCLUSION

Non-critical systems in railways are important but sometimes not taken seriously. The correct information provided to the passenger greatly add to the comfortable and reliable transportation experience. So, considerable efforts are made to provide such information to passengers in timely and error free manner.

Extraction of train movement data form critical systems is almost a must in high speed railway lines. But this kind of extraction must be done in such a way not to endanger critical system in any way.

Solutions presented in this paper are based on cyber security imperatives in rail IP networks.

Accurate train position information, which we can obtain from critical infrastructure, can enable us to develop services for passengers as well as for various agencies and opeartors. The development of the services would have to follow the development of modern communications, mobile applications, etc., so in any case the maximum protection of critical and non-critical systems must be achieved and monitoring of it continuous.

The use of unidirectional firewalls is a step towards this goal, while a development, migration and maintenance of a network being an infrastructure for both critical and non-critical services must be a central point in both IP and Signaling departments' road map.

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APPLICATION OF INTELLIGENT AGENTS ON HIGH SPEED LINES IN RAILWAY TRAFFIC

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Abstract *– The main task of the railway company for passenger transport is safe transport in the shortest possible time. The application of modern internet technologies can reduce the travel time from point A to point B. The starting point is the work on the reconstruction, construction and modernization of the infrastructure capacity of the railway. This paper presents a model that includes the modernization of railway infrastructure, equipment and devices with the installation of electronic signaling and safety elements, which also includes an electronic system for management, supervision and control. The application of new technologies (intelligent agents) should provide the basic function of traffic, ie to provide conditions for orderly and safe train traffic. In addition to the modernization of the railway infrastructure, trains (electric motor trains) must be innovated by the European Train Control System (ETCS).*

Keywords – railway infrastructure, electric trains, transport safety, intelligent agents.

1. INTRODUCTION

The safety and orderliness of railway traffic in modern business implies the application of advanced innovative computer technologies that are based on the Internet [1],[2],[3],[4],[5]. In this paper, the applied technology is presented for the purpose of traffic safety on high-speed railways.

The authors in the paper [6] note that ensuring safety and quality of service are two critical topics in communication-based train control data communication systems that can directly affect safe train traffic. As a new generation of application infrastructure and emerging strategic technologies, the Internet of Things (IoT) is an inevitable trend that is integrated into the rapid development of high-speed railways. At the core of the concept are the key technologies of IoT, and then the requirements for IoT are analyzed. Based on these concepts, a system architecture of IoT has been proposed in order to expand the in-depth applications of IoT in various fields [3],[7].

The application of techniques based on artificial intelligence (AI) has a strong potential to improve safety and efficiency in data-driven intelligent transportation systems (ITS) [8].

This paper will present an analysis of the application of intelligent agents in railway traffic, the modernization of the railway infrastructure, the speed on certain parts of the railway, the length of the stopping distance, the characteristics of innovative remote control devices, the components that make up an intelligent agent, as well as a graphic representation of the functioning of an intelligent agent on the railway Belgrade Centar - Novi Sad.

2. INTELLIGENT AGENTS ON HIGH-SPEED RAILWAYS

Increasing safety on high-speed railways involves less and less the employee (man) in the realization of the necessary activities for the supervision, control and orderliness of traffic. There is a need for machines, devices and procedures to be planned in advance and completely replace employed operators who participate directly in traffic. In accordance with real needs, IT engineers as well as railway company managers plan new strategies and systems for train management.

High-speed train control systems are based on Internet communication and are growing directions for the development of future train control systems. With the adoption of wireless communication network techniques and technologies, train control systems are more vulnerable to cyber attacks. It is noticeable that jamming attacks, which aim to lower the quality of

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train traffic. This will have a serious impact on the efficiency of train control work. Current research on control system security makes it difficult to model the train control system, and the current countermeasure schemes against jamming attacks are not designed for the working mechanism of the train control system [3],[9].

Intelligent agents represent a set of machine learning, expert systems, applied technologies and predetermined organizational processes for the implementation of safety processes on high-speed railways.

Here it is shown the high-speed trains on certain routes as well as the devices that make up the basic function of an intelligent agent.

2.1. Train traffic route, speed and stopping distance

In the middle of March 2022, an electric double-decker set of Inter City trains named "Soko" was put into service on the route from Belgrade to Novi Sad and back. For the traffic of these trains, works were carried out on the reconstruction, construction and modernization of infrastructure capacities.

Due to the modernization of equipment and devices in the stations on the mentioned route, new electronic signaling and safety devices of the "DS6-60" type with an electronic control and monitoring system of the "MMI" type manufactured by "CRSC Research & Design Institute Group Co" were installed. Ltd.” from the Republic of China.

With this technical innovation, all official positions on this part of the railway are included in the central system of control and management of train traffic. In short, the official place for managing and controlling train traffic is called remote control. The newly installed technologies for the functioning of remote control devices are of the "FZt-CTC" type, produced by "CRSC Research & Design Institute Group Co." Ltd.” from the Republic of China. The application of new devices foresees the length of the stopping distance in the following sections:

1. On the part of the Belgrade Centar - Batajnica railway line, 1000 m,
2. On the part of the Batajnica - Novi Sad railway 1500 m and
3. When trains are running in ETCS mode, the stopping distance is at least 2500 m

In addition to the above, the maximum permitted train speeds on the railway are:

1. Belgrade Center - New Belgrade 100 km/h,
2. New Belgrade - Batajnica 120 km/h
3. Batajnica – Nova Pazova 200 km/h Novi Sad track, 120 km/h Šid track
4. Nova Pazova- Stara Pazova 200 km/h, 160 km/h on Šida track
5. Stara Pazova – Karlovački Vinogradi 200km/h
6. Karlovački Vinogradi – Petrovaradin 160 km/h
7. Petrovaradin - Novi Sad 100 km/h

2.2. Characteristics of innovative remote control devices

The signaling systems installed on the part of the Belgrade Centar - Novi Sad railway consist of the following parts:

1. Cell electronic (computer) signaling and security devices (offices are provided with electronic security devices of the "DS6-60" type with an electronic control and monitoring system of the MMI type, which enables a graphic display of the state of all signal elements on the station board, as well as displaying operational tips, alarms of faulty systems and equipment, at the same time recording the state of elements and set commands in real time),
2. Remote control systems (traffic executive and supervisory staff, devices, equipment for the functioning of the orderliness and safety of train traffic),
3. A central system for monitoring the operation of signaling devices (it should ensure safe use and strengthen the management of connections between signaling equipment, monitor the status, detect hidden potential dangers and help solve signaling equipment errors and improve the level of maintenance),
4. Turnout heating systems (installed in all stations where the train master can turn on/off the turnout heating at the control desk, a remote control panel for the turnout heating system based on SCDA is installed on the remote control and
5. European train control systems (ETCS)

The main role and task of the device "FZt-CTC" is to command and manage the movement of trains and shunting trains on the part of the Belgrade Centar - Novi Sad railway.

The device includes traffic signal technologies and has two basic modes of operation: from the remote control using the device i forced download of the cellular mode of operation.

3. APPLICATION OF AN INTELLIGENT AGENT ON THE ROUTE BELGRADE CENTER - NOVI SAD

This paper shows the application of an intelligent agent in order to increase safety in railway traffic on the Belgrade Centar-Novi Sad line. Intelligent agent represents a set of different scientific disciplines that include machine learning, expert systems, applied technology and organizational processes (Fig.1.).

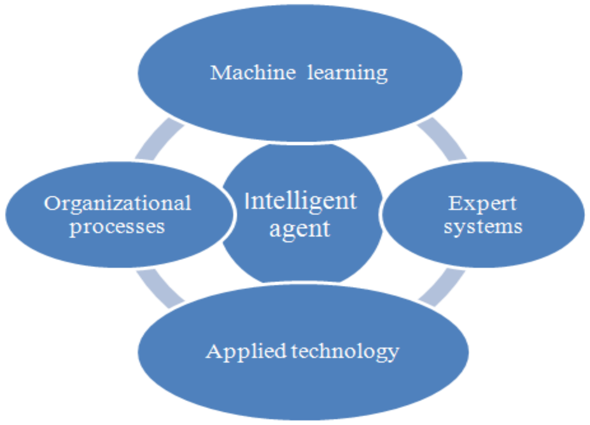

Fig.1. Components of an intelligent agent

Machine learning is directly connected to expert systems and databases where the computer "acquires" the data it should accept and how it should react in order to increase security. Expert systems and its structure determine the way of use and the area of application through the knowledge base and locking mechanism. Applied technology includes the infrastructure and architecture used in railway traffic, as well as the innovative technologies of the European train control system. Organizational processes are determined by IT engineers with the needs of the railway company, how and in what way the integrated components of the intelligent agent should function.

The centralized railway traffic control system overlaps hierarchically through interconnected devices and fixed block installations, which enables traffic control between railway stations and is the core of the management and organization of railway traffic. The centralized management model and the related implementation actions concerning traffic control are carried out by intelligent agents, and the placement of routes or changes in signaling aspects are tasks performed by remote control from appropriate positions. Network management includes centralized traffic control for an optimal system with the following functions: computer network design; maintenance and control of local network security; repair of faulty or malfunctioning system equipment; proper local network management (IP, communication equipment, specific applications); maintaining appropriate quality standards in terms of network configurations [10].

As part of the reconstruction, modernization and construction of infrastructural capacities on the part of the Belgrade Centar-Stara Pazova railway, the installation of a new electrotechnical infrastructure (electrical traction plant, signal-safety and telecommunication devices) with the European train control system (ETCS - European Train Control) was carried out System), which is part of the European Rail Traffic Management System (ERTMS).

The European Train Control System (ETCS) is an upgrade to the conventional (national) signal-safety system. Control of train position and control of train integrity is performed by track devices of the conventional signal-safety system (axle counter system) and is not part of the ETCS system (Fig. 2.).

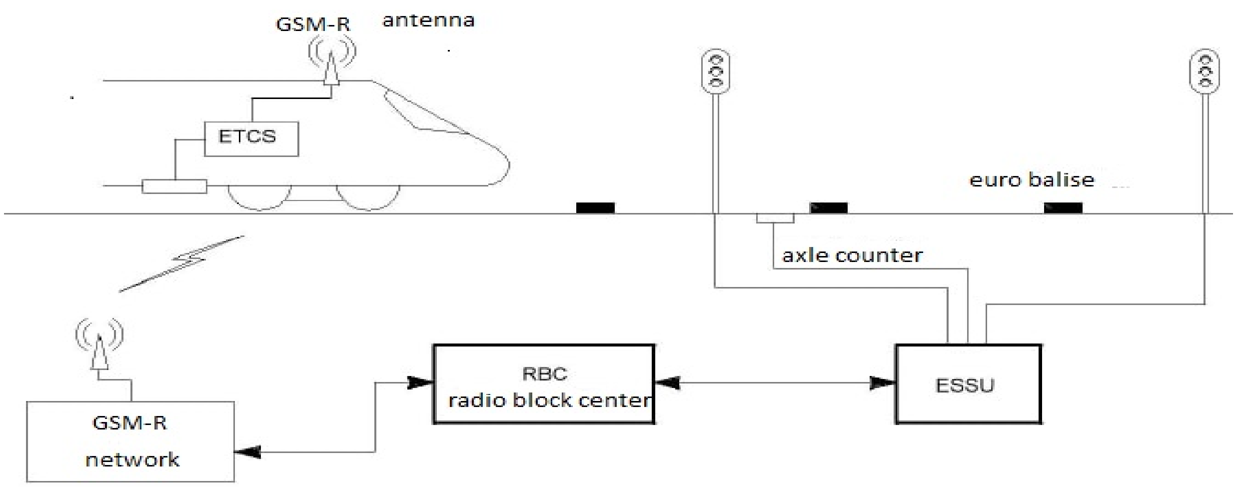

Fig.2. Intelligent agent configuration

The railway equipment of the ETCS system consists of the following elements:

1. Eurobalise – railway transponder for the transmission of information between tracks and vehicles;
2. GSM-R (Global Mobile System-Railways) network – a global mobile system that performs the function of information exchange between RBC and train equipment;
3. radio block center (RBC - Radio Block Centre) - based on all the necessary static and dynamic data, it generates a driving license (MA - Movement Authority);
4. Key Management Center (KMC - Key Management Centre) - railway component that is responsible for managing cryptographic keys on the railway, in order to enable secure radio transmission of ETCS data;

5. public key infrastructure (PKI - Public Key Infrastructure), including appropriate protocols for authentication and transmission.

Two-way data exchange between the built-in ETCS subsystem in the electric motor set and the RBC is achieved via a wireless GSM-R network. The RBC generates the driving permit (MA), the detection system (axle counters) control the occupancy of the cell and space sections, and the balises determine the location of the train. In the RBC, there are maps of driving routes with all static data of the railway section in question, such as the maximum permitted speed, gradient, track condition, locations of balise groups, etc. Through the direct connection between the RBC and the cellular signal-safety devices, all the necessary variable information such as the positions of the switches and signal signs are available to the RBC. With this information, the RBC calculates the driving permit for each train controlled via ETCS and revokes the previously issued driving permit. Thanks to the previously described measures, the ETCS system, when controlling the train's movement, also realizes protection against exceeding the speed of the train's movement.

In vehicles equipped with the ETCS system, the cabin signaling of the ETCS system has priority over the signal signs of the light signals. The ETCS train control system is divided into two parts: track and locomotive.

4. CONCLUSION

This paper presents the possibilities of applying intelligent agents in railway traffic on a section of the high-speed railway (Belgrade Center - Novi Sad). The applied technology provides a starting point for the greater representation of intelligent agents in all transport processes where the employee (human resource) is not able to react in a timely manner in order to increase safety on high-speed railways.

The transfer of information between the components of the intelligent agent must function continuously in order to avoid interruptions and suspensions of railway traffic. Future research directions must include alternative power supplies in order to save electricity so that the system works 24/7.

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XX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
RAILCON '22

RAILWAY SERVICES SOLUTION IN SITUATION OF TRANSMISSION SYSTEMS' FAILURE

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Abstract *– Infrastructure of Serbian Railways possesses certain services, relying on the IP network, extremely important for the enterprise, but not marked as critical for train movements. The chosen principal regime for L3 VPN connections, IPSec tunneling, xDSL links combined with QoS, gigabit FO links, and virtual servers are described in the paper. This paper deals with these services giving the option for their online survival, regardless of the failure of certain points in the transport/transmission part of the network.*

Keywords – non-critical services, survival of services, failure.

1. INTRODUCTION

Applications, in recent days have become primary part of bussiness. It goes without saying that this pattern is established in traffic and transportation enterprises as well. In this environment a significant number of procedures and Rulebooks needed adjustments in order for these applications to be used in safe and secure manner and in order to use and present sensitive information towards users and employess in adequate ways. Securing the access to data without interruptions led to the establishment of new infrastructure going beyond the classical model and moving into a hybrid model. Hybrid model implies the use of modern technologies with mandatory reliance on what already exists overlaying the current trustworthy technologies used in data transmission and the use of everything at hand.

The IP network elements are in railway environment in Serbia recognized as part of the railway infrastructure, and are thus regulated in numeruous railway/common laws (directives), regulations, rulebooks, standards etc. But in majority of day-to-day exploatation of this network railways also relay on common IP networks knowledge base and best practice [1-7]. The solutions presented in this paper are a part of internal roadmap set and adjusted per need internaly within the Infrasructire of Serbian Railways IZS.

2. INFRASTRUCTURE

When talking about the applications not directly related to train movement control (but relevant for registering the train movement), some apps come to light like: various authentifications, recording the trian movement, international trains movent registering and charging, archiving the extraordinary events ets. The access and storage of these data is regulated with server systems.

At the moment server infrastructure is defined as virtual, using servers of the latest generation and fast discs as storage space. Virtualization is not a new technique, but over time the type of virtualization and the corresponding hardware have been harmonized so now we can say that everything is defined under the same software enabling unified control, monitoring and operation of virtual servers (VmWare). The paper will onwards describe the access to data and cases of outage.

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Fig.1 depicts the network infrastructure responsible for accepting and forwarding queries to servers. It is clear that redundancy is established on higher levels, in order to prevent outages.

redundancy is provided for (but not limited to) power supply, links and some devices at the level of communication and server equipment.

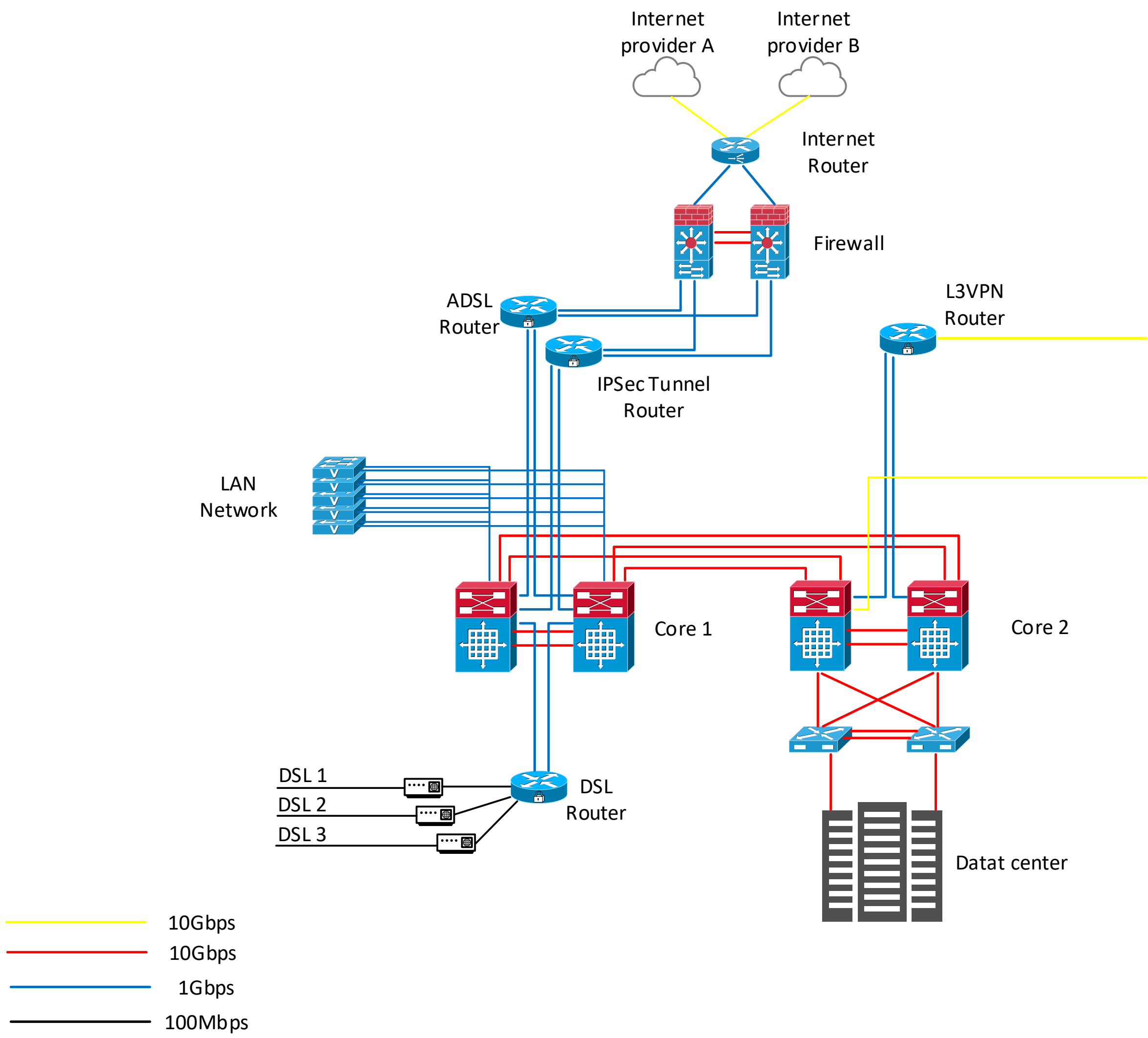

Fig.1. Network core infrastructure

Sharing is also done – power supplies, ISP and other links. Core of the network holds links with capacity 1Gbps up to 10Gbps, matching the type of traffic.

It can be seen from the figure that all known principles of connecting are present and are included in the system of data transmission and access to information. This will allow the stations to have the option of accessing the data even in the case of failure of certain transmission systems.

Fig.2 defines all types of data transmission, using which it is possible to reach central servers. It should be noted that MPLS network of the newly built/reconstructed railway lines is not included in this analysis.

Fig.3 defines how the very principle of access to data centers is configured and how the system is protected against outages. Earlier, it was said that

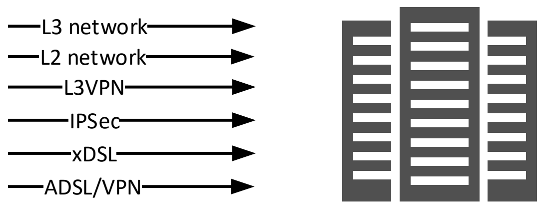

Fig.2. Different types of data transmission to central servers.

It could be said that the primary site contains all server systems and is responsible for real-time data availability. From the figure could be seen that most of the server systems are located there. In another location, there is a server system that is a replica, but only for critical servers, i.e. services. An L2 structure with speeds of 10Gbps is defined between the two data centers. Also, an L3 structure is defined between the data centers, for the purposes of routing and access

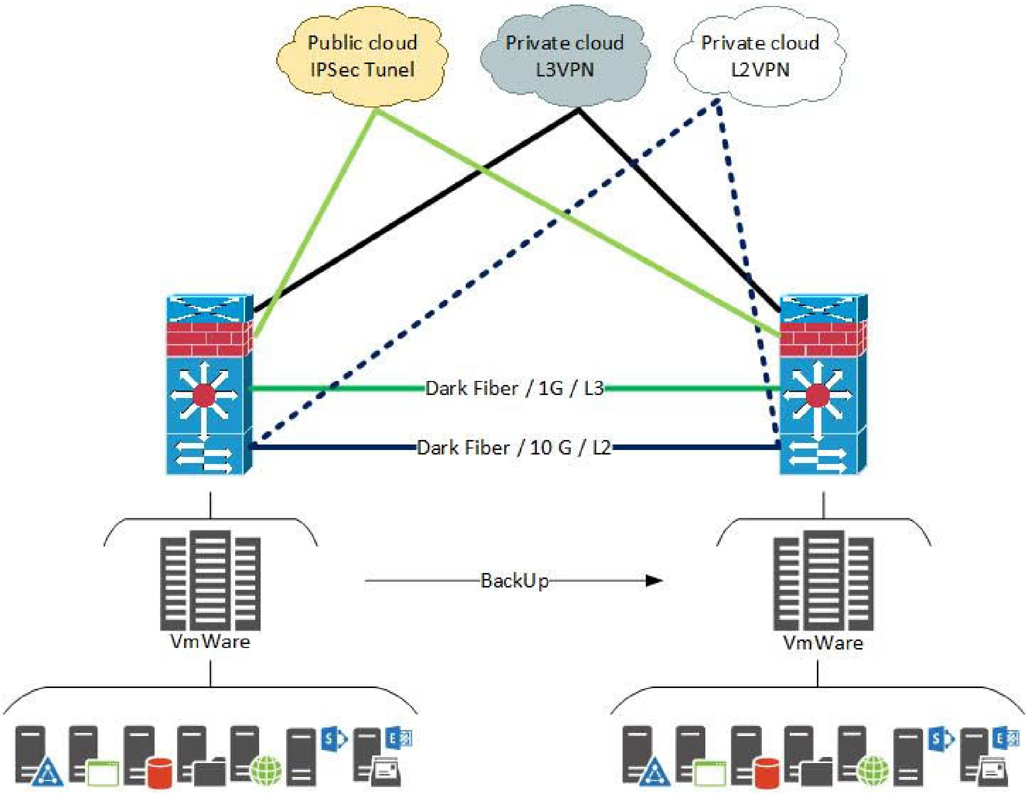

Fig.3. Data centers' mutual connection

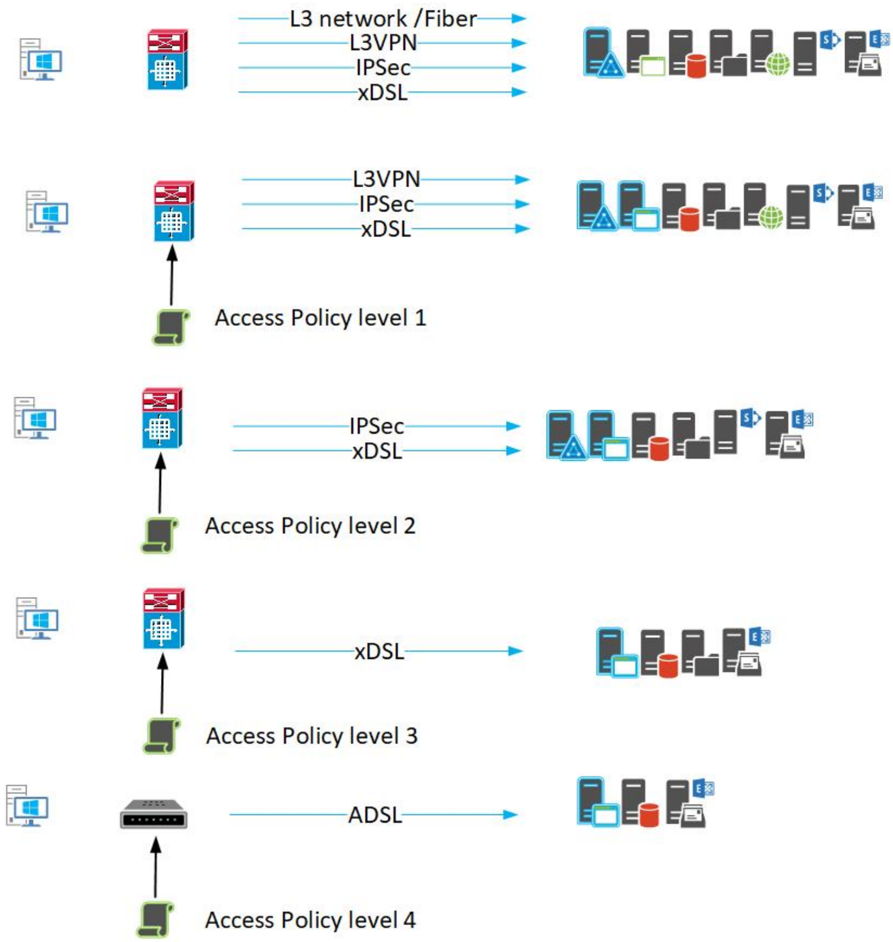

Fig.4. Data transmission connections

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to servers.

The secondary location is activated only if the server structure or data center communication equipment fails at the primary location. If the server system fails at the primary location, the server system at the secondary location is activated for critical services. In that case, it will remain active until the complete aveilability of the primary location is acheived. This means that it will remain active until the backup and restoration of the data is done, and deactivated only after the activation of the primary location is complete and confirmed.

Regarding access to critical data by employees from all over Serbia, it is possible but with certain criteria. Namely, access to certain servers is enabled based on the defined speed from the location as well as the number and type of redundant links. If the location has several types of connections, the settings are configured so that the primary link is the fastest, etc. When the primary link fails, the secondary link is activated, and so on.

Fig.4 depicts access to servers based on predefined connections.The next step in defining the connection of the server net, at the level of the MPLS structure, is in completion and it will remove all the shortcomings of the existing structure. The system will enable 10Gbps speed between the centers. 3 data centers will be defined forming a ring configuration. This will make possible to set the option of live migration of server systems from location to location as well as all the new functionalities that come with modern operating software.

Based on what has been presented, it could be said that stations (users) that have fast connections such as optical connections, L3VPN have access to all services because access to critical services and data is not compromised. Other stations, which work on ADSL and xDSL, must have limited access to critical services only. This ensures that there is no congestion during transmission. Fig.5 defines the simplified cross section of access to server equipment. Access lists and defined QoS on the route can enable access to server equipment and work with applications with as little congestion as possible.

QoS is defined with the option of prioritizing access to application servers that provide information about train movements, as well as servers that are responsible for checking credentials for logging in and access to certain equipment and applications. In the current organization, the common voice communication system was not propagated through TCP/IP, which further facilitated the organization of QoS for application servers.

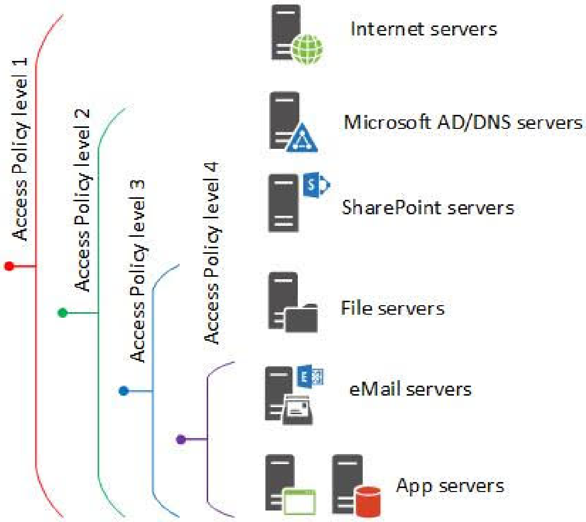

Fig.5. Access to server structure based on policy level.

3. CONCLUSION

The construction and implementation of IP network in railway environment is a challenging project demanding fast and flexible solutions jet expected performance. The additional issues are related to a specific need in a time span covering reconstructions of several lines at the same time, the need for reliability and establishment of interconnections of various vendor equipment.

The presented solution, is common solution using all at hand to reach the end users. Only the fact that the data considered is not related to vital railway systems allows the network to not be overly redundant.

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Vehicle and infrastructure maintenance

THE TREND OF TRAIN COUPLING FAILURE ON SERBIAN RAILWAYS IN 10 YEAR PERIOD

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***Abstract** – This paper presents an analysis of train coupling failure on the Serbian Railways and displays a trend of characteristics over 10 year period. The impact of changes in the organization of exploitation and maintenance and led by the introduction of Entity in Charge of Maintenance (ECM) and reconstruction of Serbian railway company into 3 separate entities as well as some differences and aging in rolling stock induce certain changes in the parameters of train coupling failure. The analysis is done based on parameters of train configuration and driving specifications. Only freight trains with single traction locomotives are considered. The distribution of coupling failure along the train, driving regime and velocity is comparatively discussed related to the values from the previous period. Load status, as well as the length and mass of the trains in the extended collection, correspond to a certain distribution. Causes of failure and damages to coupling and draw gear indicate specific conditions leading to failure. Analysis significance helps the systematization of failure features and sets the ground for defining the parameters that impact failure and determining their quantification.*

Keywords – railway, train, screw coupling, draw gear, couplers failure, train breaks apart.

1. INTRODUCTION

The analysis of train coupling failure (that includes coupler and draw gear) on Serbian railways public network aims to:

- classify coupling failure cases and systematize causes, circumstances and consequences;
- quantify the structure, place and conditions of coupling failure to determine what leads to failure increase;
- take into consideration the impact of coupling failure on railway traffic safety,
- predict the coupling failure and propose measures to reduce them.

Rolling stock of railway operator "Serbia Cargo" partially includes rolling stock of previous national operator "Serbian Railways", whereby their number was reduced from approx. 330 from 2011. to about 230 in 2020. Number of freight wagons were reduced from almost 8500 in use of "Serbian Railways" in 2011. to approx. 4000 wagons in use of "Serbia Cargo" in 2020. with almost 1900 wagons in daily operation. Rolling stock in "Serbia Cargo" are over 40 years old, while only new locomotives (16 engines Vectron) were procured in 2020. "Serbia Cargo" also rents a number of vehicles from other railway operators in Europe and a certain number of foreign vehicles, according to the GCU (General Contract of Use for Wagons), also operate on the Serbian railways. Therefore, the analysis of train coupling failure does not have a purely national character and is not unambiguously defined.

Only relevant cases of train coupling failure were analyzed, therefore uncoupling of semi-automatic couplers was not taken into account, as well as other special cases (3,3%).

There were only a few train coupling failures on passenger trains, so this analysis excludes them. From 2007 to 2011 the average number of coupling failures on "Serbian Railways" freight trains was 40,2 cases [1] per year (Fig.1). That number didn't decrease significantly from 2016 to 2020 and for "Serbia Cargo" freight trains the average number of coupling failure was 36,4 cases per year [2]. Reduction of the

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total number of accidents and incidents in the period 2016-2020. increase train coupling failure (on average) to 13,9% per year.

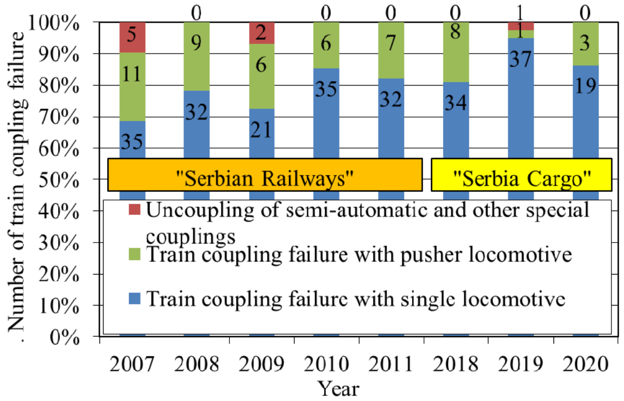

Fig.1. Number of train coupling failure of freight trains of the operators "Serbian Railways" and "Serbia Cargo"

2. COUPLING FAILURE CHARACTERISTICS

There has been an increase in the number of damaged foreign wagons due to coupling failure from 35,4% to 46,6% in the period from 2018 to 2020 [3], compared to 10 years ago (Fig.2). This is primarily a consequence of more foreign wagons operating on the Serbian railway infrastructure.

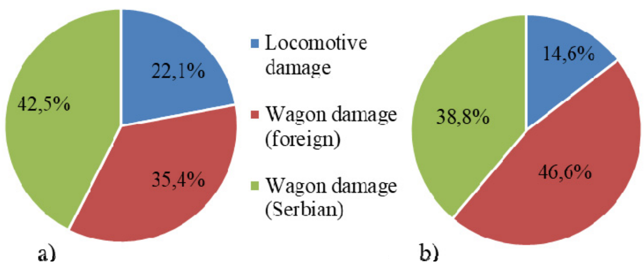

Fig.2. Frequency of damaged railway vehicles in case of coupling failure, a) from 2007 to 2011, b) from 2018 to 2020

The frequency of locomotives damage has decreased from 22,1% (Fig.2a) to 14,6% (Fig.2b) in observed 10 years period. This indicates that a large number of coupling failures occur between the locomotive and the first wagon in the train. Also, over 50% of damaged locomotives must be repaired in workshops (Fig.3), which further increase the expenses of the incident and can lead to traffic closure.

Ten years ago, as many as 59,1% of cases of coupling failure on freight trains were on the first third of the train length (Fig.4.a) of which 26,2% are coupling failures between the locomotive and the first wagon, and 32,9% between the first wagon and the first third of the train length [1]. Only about 17,7% of train coupling failures were between the first and second third of the train length. A slightly different distribution of coupling failure was in recent years, where in 38,3% of cases coupling failures were on the first third of the train length (Fig.4.b), of which 16,0% are coupling failures between the locomotive and the first wagon. Almost 40,4% of coupling failures were on the second third of the train length compared to just 10,6% on the last third.

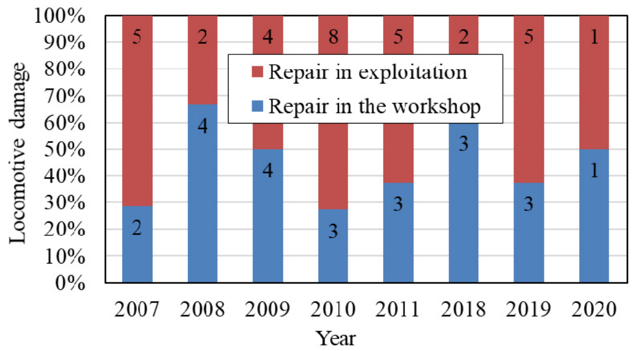

Fig.3. Locomotives damage in case of coupling failure

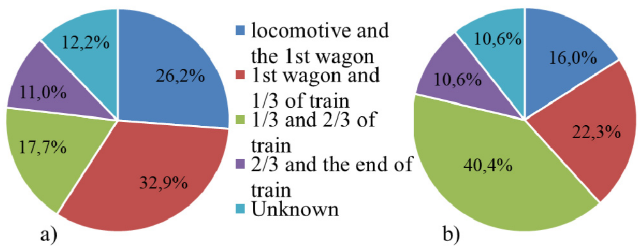

Fig.4. The distribution of coupling failure along the train, a) from 2007 to 2011, b) from 2018 to 2020

Coupling failure between the locomotive and the first wagon mostly occurs during traction, while other cases mainly occur during braking or changing of direction. From 2018 to 2020 decrease in the number of coupling failures in the front part of the train, and increasing in the middle of the train (Fig.4), was caused by a larger number of coupling failures during maneuvers (pushing) that were taken into account.

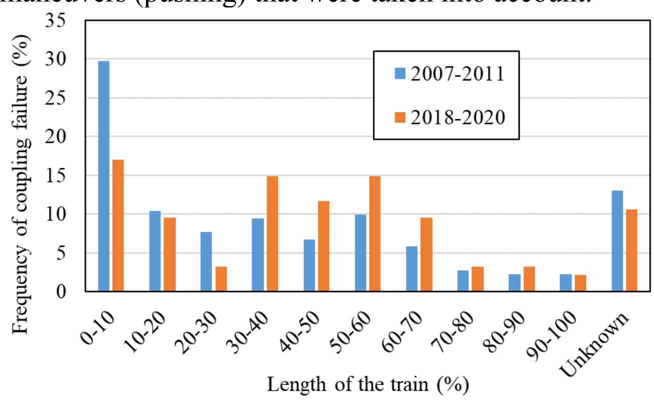

Fig.5. Frequency of coupling failure in the train

Most coupling failures occur during braking, due to large longitudinal forces, even 56,1% 10 years ago and 41,0% recently (Fig.6). Pulling regime had a similar effect on coupling failure 20% to 23% in both periods, while maneuvering has significantly more influence on coupling failure recently than before

(Fig.6).

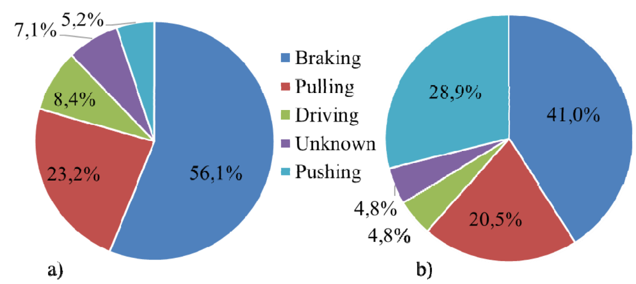

Fig.6. Driving mode before coupling failure, a) from 2007 to 2011, b) from 2018 to 2020

Ten years ago coupling failure mostly occurred at train speed between 10 and 20 km/h (34,2% cases - Fig.7) [3], while recently most coupling failures occurred at speeds up to 10 km/h (38,6%). The number of coupling failures decreases with increasing speed, so as many as 58 ÷ 65% of coupling failures occur at speeds less than 20 km/h (Fig.7).

As low speeds and the number of starts and stops (traction and braking) are more frequent in stations and nearby, so 50% to 70% of train coupling failures occur in the station area or switchyards.

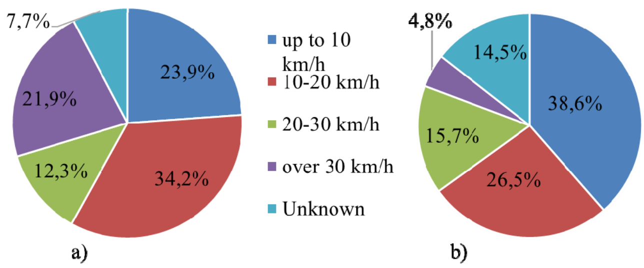

Fig.7. Train speed before coupling failure, a) from 2007 to 2011, b) from 2018 to 2020

The train characteristics that can influence the frequency of coupling failure are the number of wagons, the length, and weight of the train, the state of loading, the schedule of loaded and empty wagons in the train, and others. The smallest number of wagons on freight trains that have coupling failure is 8 to 15 and the largest number of wagons is 43 to 51, while in the last three years the number was between 9 and wagons (Fig.8).

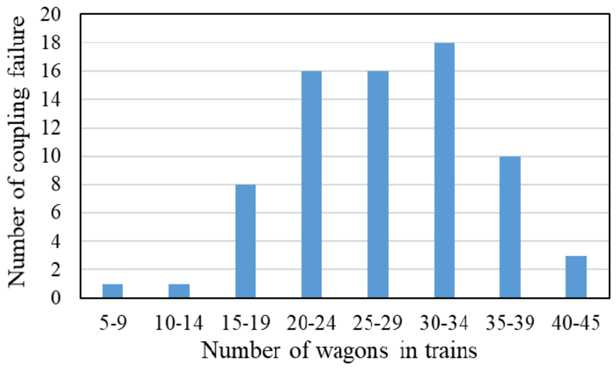

Fig.8. Number of wagons in trains with coupling failure from 2018 to 2020

Consequently, as average freight train in the last ten years had 26 to 27 wagons [4], length of broken trains ranged from 152 m to 720 m. The average length of trains breaking apart was about 400 m. It can be concluded that the frequency of train coupling failure increases with train length over 500 m (Fig.9).

The masses of trains that have coupling failure range from 336 t to 2333 t (Fig.10). The average gross weight of one train in 2009 was 926 t [3], and of a train that break apart 1354 t, similar to the last few years.

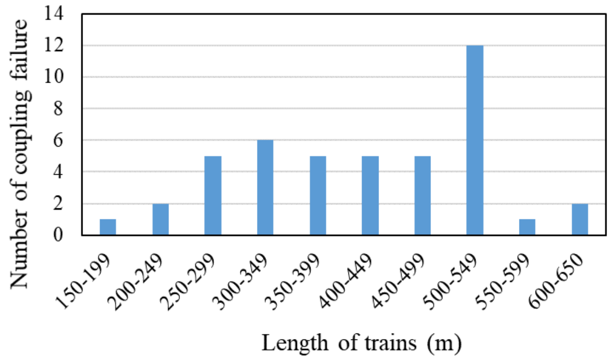

Fig.9. Length of trains with coupling failure from 2018 to 2020

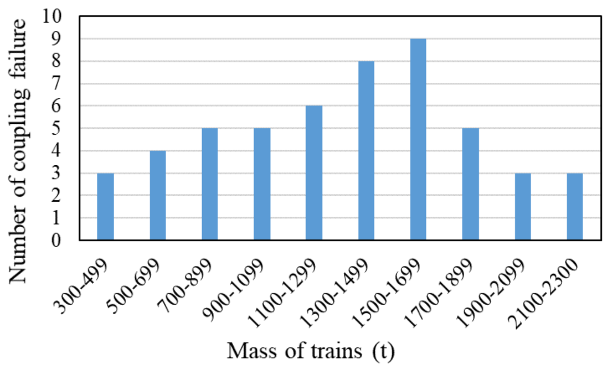

Fig.10. Mass of trains with coupling failure from 2018 to 2020

The frequency of coupling failure is somewhat higher for trains with all loaded wagons (26,6%) related to 16,5% for trains with all empty wagons. Trains with diverse lodes (both loaded and empty wagons) have 25,3% frequency of coupling failure, but in almost a third of cases loading data were not available.

The official analysis of train coupling failure on Serbian railway, states that the cause of failure, in over 50% of cases, was the fatigue of material (Fig.11), such as changed material structure, loss of connection parts, and other irregularities related to the material of failed parts. Irregularities in driving are listed in 15% to 18% of cases as the cause of coupling failure. Variations of train composition, tightness of screw coupling, as well as the vehicle condition (technically in order) make 9% to 20% of coupling failure causes. The increase of the material in the last ten years, as the main cause of coupling failures from 50,8% to 59,6% cases, indicates that there has been a decrease in the quality of diagnostics in the maintenance of coupling systems (including draw gear).

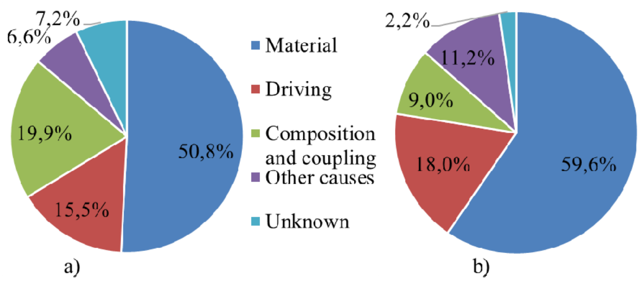

Fig.11. Causes of coupling failure, a) from 2007 to 2011, b) from 2018 to 2020

The consequences of the coupling failure and train breaking apart could be direct costs of the material (spare parts and repair), but also include indirect costs (delay of a broken train and other trains on the the line). They also include costs related to traffic disruption and organizational change. From 2007 to 2011, the direct material costs of breaking trains apart were up to 1000 euro, [1] and the traffic closure on the rail line section lasted on average 3 to 4 hours. Similar was from 2018 to 2020, with direct material costs between 400 and 900 euros, and the traffic closure between 4 and 5 hours (Fig.12) [5]. These consequences do not include the total costs of keeping trains and the engaged train route, which do not happen at every break, but can amount to 3000 euro and higher.

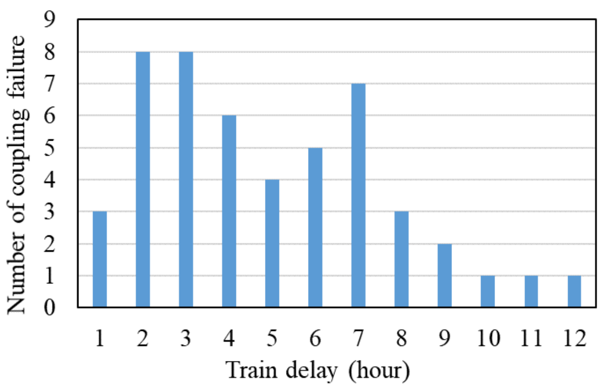

Fig.12. Train delay after the break from 2018 to 2020

The conditions of technical inspection and the level of the technical quality of wagons in the exchange between railways in Europe are defined in Annex 9 of GCU. It attributes all the damage caused by the accident (not wear and tear), with a recent breakdown, without signs of fatigue, to inadequate handling of freight wagons by the railway company of vehicle users. Thus coupling failure can have significant financial consequences as all fractures during breaks, in which there are no clear traces of fatigue, or wear on broken parts, are considered the responsibility of the user's railway operator.

During the coupling failure, in majority of cases the reason were parts of draw gear in 55,0% of cases and coupler in 36,7% of cases (Fig.13). The failure of other parts was significantly less - about 8,3%. In the last three years, the failure of draw gear elements has increased to as much as 63,9%, while the failure of coupler elements has decreased to 26,9% (Fig.13).

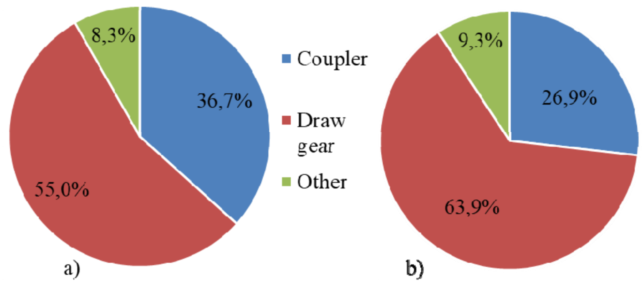

Fig.13. Coupling failure parts, a) from 2007 to 2011, b) from 2018 to 2020

3. CONCLUSION

The characteristics of train coupling failure over 10 years show a decrease of locomotive damage and frequency of coupling failure in the front part of a train, as well as an increase of coupler and draw gear fatigue. Since coupling and draw gear are standard constructions, and also inspected with regular maintenance, the percentage of failure caused by material fatigue is extensive. Significantly, the frequency of coupling failure due to train driving has not decreased.

ACKNOWLEDGEMENT

The research work is done thanks to the management of the railway operator "Serbia Cargo" which provided access and insight into train coupling failure cases.

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XX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
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WELDING WITHIN THE MAINTENANCE/REPARATION OF RAILWAYS IN SERBIA

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Abstract *– Serbia is at a turning point in the modernization of the railways of the Republic of Serbia, especially trains and infrastructure. As for the railways, work is being done on the adaptation of the former main routes, many of which are currently inactive. The paper presents existing and applicable rail welding processes, technological procedure of repair welding and quality control of the welded joints.*

Keywords – Rail, Repair, Surface Welding, Maintenance.

1. INTRODUCTION

Railway is considered the safest transportation mode compared to other means of transportation [1] but the railway infrastructure is a complex system. It comprises systems such as tunnels, bridges, earthworks and track structure. Track structure is the most fundamental railway infrastructure system. It comprises components such as rails, sleepers, ballast, and fasteners, out of which rails are the most critical and maintenance demanding component of the track structure as they are in direct contact with the train wheels.

Many researchers have done their researches of welding as part of railway maintenance and repair. Feng [2] presents problems in the work of replacing damaged rails and their welding into the existing continuous welded rails (CWR) using a mobile electric resistance flash welding process and thermal treatment after welding. A comparison is made of the applied approaches used in several major national railways around the world. Stevanović [3], in her master's thesis, described the technology of repair and surface welding of the turnout rail bound welded frog and processed the results of testing its strength. Popović *et al* [14] presented the application of self-shielded and flux-cored wires for welding in the atmosphere of CO_2 gas used for welding rails. They propose the recommended technological procedure and self-shielding wire that give the best results in their opinion. This application is confirmed by the work of some other researchers [14]. Sedmak *et al* [7] showed that the repaired rails (by reparative welding), due to the improved microstructure and resistance to the cracks-formation, have better mechanical properties compared to the original ones. Furthermore, Kozyrev *et al* shows in their work [4], through the analysis of modern procedures, significant influences on the quality of the welded joint of repaired CWR.

The welding procedures used for repair, the welding technology used for the welding procedures and the required quality of the repaired rail section have to be directly specified in order to get fulfilling results.

2. DAMAGE TO RAILS

On the railways of Serbia, wear and tear is the biggest damage infliction processes to the rails, and it is especially seeable on the joints.

Today's rail failures (based on the nature of their occurrence) can be divided into the following groups:

- fatigue cracks failure;
- rolling contact fatigue cracks;
- wear failure;
- material deformation failure and
- shear failure [16].

Replacing defects with a new piece of rail is expensive and not always desirable because it introduces new discontinuities in the track structure in the form of two weld seams that worsen the properties of the hot-rolled rail.

3. MAINTENANCE OF RAILWAY TRACK

The rulebook on technical conditions and maintenance of railway track [15] defines the

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maintenance and determines periods for the regular inspection and measurement of the tracks in the Serbian Railways.

Although most internal defects give some external indication of their presence, they cannot be reliably determined by visual inspection. They are determined using ultrasonic detection and eddy current testing.

4. RAIL WELDING METHODS

The most common welding processes applied to rails are: arc, aluminothermic and resistance welding.

Standard arc welding procedures, such as shielded metal arc welding (SMAW), gas metal arc welding (GMAW), and possibly flux-cored arc welding (FCAW), can be/and are used for welding and repair welding of railway track components.

4.1 Aluminothermic welding

Aluminothermic welding (Fig. 1) is used for CWR in the field, and less often in the plant. Aluminothermite is a mixture of iron oxide (Fe_2O_3) and aluminum (Al) [9]. The mixture is placed in a refractory vessel and is heated to 1300 °C.

Molten steel flows into the mold, welding the rail ends, which are previously heated with a flame to a temperature of 1000 °C – 2000 °C. After removing the mold, only the surface of the rail intended for the rolling of the wheels is sanded.

Fig. 1. Aluminothermic welding (with melting) [10]

4.2. Electric resistance welding (ERW)

It is used in the railways in the form of flash welding, and is performed by automatic machines. When the melting temperature of the steel is reached, the machine presses the ends of the rails towards each other with a force of 350 kN to 500 kN, and with such pressure force, the joint is achieved. The thickening of the rail at the point of welding is removed by grinding. It is possible to perform the same welding method outdoor in the field, where the generator is located in the wagon.

4.3. Arc welding

The quality of the weld largely depends on the expertise of the welder [11]. The welding of rail assemblies can be done well in the workshop, but it is very difficult to make a good seam in the field.

4.4. Gas welding

This welding process can be used in the field or in the workshop [11]. Using the flame from an acetylene torch, the material from the high-alloy steel wire is applied to the welding object, which was previously heated to the proper temperature by the same torch.

5. THERMAL TREATMENT AFTER RAILS AND TURNOUT PARTS WELDING

Thermal treatment must not cause external and internal deformations of turnout parts [8]..

Heat treatment is performed according to a procedure that can be: annealing, tempering and pearlitization.

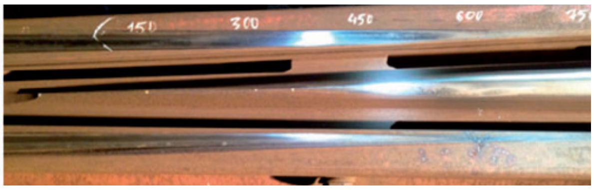
As for turnouts, the material for the frogs to be welded must undergo annealing within 48 hours after welding. If annealing cannot be started after welding, but much later, careful cooling in still air and subsequent annealing must be carried out. The running surfaces and profile of the parts are improved by either softening or pearlitizing.

6. REPAIR WELDING OF RAILS

One of the important areas of modern welding technique is surface welding - the application of molten metal to the surface of the base metal that has been heated to the melting temperature [14]. Welding of rails and frogs of turnouts and crossings (turnouts in the following text) in the field is a very profitable work, which significantly extends their service life [11].

Fig. 2. Welded layers [13]

It is understandable that surface welding becomes particularly interesting and profitable with CWR. It can also be used to equalize the height of the rail composition in order to obtain a flat driving surface, then to remove lunkers (holes) and fill in rough places on the driving surface of the rails. It is used for corroded and damaged points of frogs. Welding can be done by gas and arc welding method. Depending on the nature and size of the damage to the rail, the repair welding is carried out in several passes, and in one or more layers (Fig. 2). Today, surface welding is standard practice in railway in almost whole Europe.



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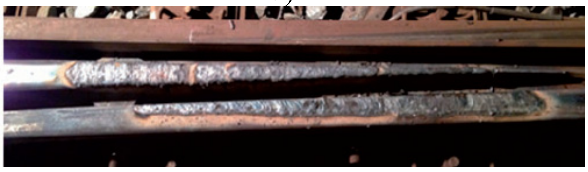

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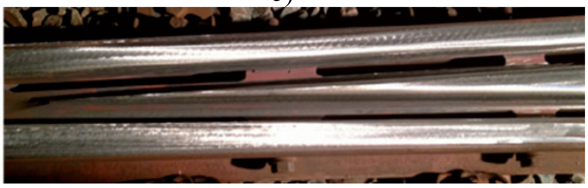

d)

Fig. 3. Frog reparation: (a) before; (b) defects treated by the machine; (c) welding done; (d) polishing [12]

6.1 Materials for making rails

A typical rail is made of high-carbon steel, 0,4 %C - 0,8 %C, where high hardness and wear resistance are achieved at the expense of poor weldability and toughness [14]. Due to their pearlite microstructure, these steels typically have low toughness and crack growth resistance, making them prone to rolling contact wear and fatigue [7].

On the tracks of the Serbian Railways, are installed rails with a minimum tensile strength of 700 MPa [6]. Rails with higher tensile strength were installed only in sharp curves, in tunnels, on large slopes, in places where trains are braked and stopped, at turnout elements and other special track constructions. Damaged parts manufactured from high carbon steel can be surface welded despite their poor weldability. With the correct choice of welding technology, it is possible to obtain a microstructure with improved properties that corresponds to the new generation of steel, i.e. the bainitic microstructure. In this case, the surface welded layer has a higher resistance to crack growth, which improves the overall reliability of the rails and the turnout frog. Such technology is not only a way of reparation, but also a way of improving the initial properties of rails and turnouts.

6.2. Repair welding of rail steel

Semi-automatic arc welding processes, with flux-cored and self-shielded wires [7] are most often used for repair welding. The basic difference between them is that the first one requires an external shielding gas, and the second does not. Repair welding of rails and turnouts using a semi-automatic process has significant techno-economic advantages compared to replacement with new parts [14]. Repairing just one turnout pays for the purchase of a welding device. The most effective surface welding method is the semi-automatic one with self-shielding flux-cored wire. The entire process of reparation of the frog is roughly shown through photographs (Fig. 3).

Technological procedure of repair welding of rails

After welding, the material is annealed in the same way as before welding [13]. Before annealing, the surface should be cleaned to undamaged material. If the cracks open deeper, to a depth greater than 10% of the height of the profile, it is not recommended to carry out welding, i.e. surface welding, because there is a high probability that, due to the thermal action during preheating, the cracks will only increase due to the microstrains that arise. If this happens, such rail section must not be released into further traffic.

However, if the cracks do not spread, and they are within the permitted depth, welding can be started.

For welding, you need: equipment (generator, grinders, etc.), tools, electrode wire (electrode in the following text) for welding, qualified welding experts, and you need to know the type of basic rail material and choose and prepare the electrode.

Preparation of welding electrode

Since rail steels belong to the group of materials that are difficult to weld, care should be taken in the choice of electrode [13]. The common feature of all electrodes used for surface welding is their basic coating. This is a reason why a very high density direct current for surface welding is needed.

The basic coating of the electrode is very hydroscopic, which means that it strongly absorbs moisture from the air. The presence of moisture in the coating of the electrode is very unfavorable.

It is avoided (or minimized) by: annealing or drying-out the welding consumables.

Additional materials for repair welding of rails

Different additional materials can be used for repair welding of rails and turnouts, depending on the selected welding procedure [14].

In Serbia, arc welding with coated electrodes is still widely used. For semi-automatic welding processes, the world uses flux-cored wires that melt in a protective gas atmosphere (usually CO_2 or a mixture of CO_2 + Ar) or self-shielding wires.

Cooling after surface welding

With steel type 700 (rail group according to the UIC 860 standard), no special cooling measures are required, unless surfacing is carried out at low, winter temperatures. With steel types 900 and 1100, we must prevent sudden cooling of the welded part. This can be achieved with thermal insulation caps that are lined with asbestos. The same effect can be achieved by subsequent slow reheating with a soft flame for a few minutes. At the same time, care should be taken not to heat the material over 300°C by reheating.

In the case of highly alloyed manganese steels, preheating must not be carried out, but on the contrary, the base material must be cooled during surfacing. It is recommended to weld this type of steel in winter, at low temperatures.

7. QUALITY OF WELDED JOINTS

7.1. Inspections of welded joints in the track

Inspecions of welded joints in the railway track include: visual-direct inspection and ultrasonic inspection [15]. The most suspicious welds are taken as representative samples and subject to other additional tests. During and after welding, one should strive to obtain homogeneous properties within the welded objects [12].

7.2. Quality of heat treatment

The quality of the heat treatment is checked based on the characteristics of the heat treated parts. The following features are checked: hardness, tensile strength, metallographic tests [8].

Test report

The final report must contain an assessment of whether the results obtained during the tests are within the permitted limits provided for in the provisions of the rulebook and whether they confirm that the appropriate thermal procedure has been carried out correctly.

The final report must have reports of individual examinations attached.

8. CONCLUSIONS

It can be stated that welding as part of maintenance of railway objects is mainly repairing by surface welding. Taking into account, the rail is made of pearlite type of steel and is exposed to a complex deformed state, which leads to its degradation, surface welding is currently the dominant maintenance method for extending the life of exploitation. Considering that the frogs, whether cast or welded, are a very important infrastructural element of the railway system, and by reparation instead of replacement, significant cost savings are made without losses in reliability, but also without losses caused by traffic jams if the same part were to be replaced, repair welding is of great importance in railway maintenance.

ACKNOWLEDGEMENT

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XX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
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RISK ASSESSMENT OF COUPLING SYSTEM FAILURE ON TRAIN IN CURRENT MAINTENANCE SYSTEM

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Abstract *– Development of new management approaches on the railway, based on risk management, with the adoption of standards EN 50126-1 and EN 50126-2 provide safety management processes for railway applications. Risk factors can be determined using different risk assessment methods like FMEA, FMECA, FTA etc. or their combination. The permissible risk values based on accepted values and defined preventive measures are designed on the current maintenance plan for freight wagons. Preventive measures are established for revision maintenance which is carried out every 4-6 years. Risk analysis of coupling system failure can be different depending on the time of analysis (regulations, exploitation conditions) and the applied maintenance practice. FMEC analysis applied to train coupling systems based on regulation shows different permissible risk values that don't match exploitation data.*

Keywords – railway, train coupling failure, FMECA, risk analysis, maintenance.

1. INTRODUCTION

The introduction of new management approaches, based on risk management (RAMS - Reliability, Availability, Maintainability and Safety) was initiated on the railway with the adoption of standard EN 50126 in 1999. Development based on standards EN 50126-1 [1] and EN 50126-2 [2] provide safety management processes for railway applications with instructions and methods for their implementation. Though the application of these standards is intended primarily for new systems, it is also desirable for significant modifications and reconstructions of existing systems.

The application of the EN 50126 series standard in defining reliability and safety and the instructions for application of management based on RAMS was made as an example on wheelsets and bogies in UIC B169, RP 29 and RP 43 [3]. Risk analysis identifies risks, assesses their acceptability and, concerning the criticality level, recommcends measures to reduce risks, i.e. to achieve acceptable risk. Failures are ranked according to the criticality level, known as the Risk Priority Number (RPN).

The risk of trains breaking apart, caused by coupling failure, in railway traffic is a quantitative measure of the severity, detectability and frequency. Taking measures to reduce coupling failure is to manage improvement by preventive maintenance, quality, design and operation [3].

Risk assessment using Failure Mode and Effects and Criticality Analysis (FMECA) for mechanical components in railways and the application of the same methodology in risk assessment is based on Failure Mode and Effects Analysis (FMEA). The difference is the additional critical analysis performed after the implemented FMEA.

2. APPLICATION OF FMECA METHOD

The ranking of the severity, detectability and frequency of coupling failure for freight wagons was made according to ranks in UIC B169, RP 43 [3], where the rank have values from 1 to 10. For severity, values range from „no impact“ for 1 rank to „unsafe without warning“ for rank 10. The ranking of detectability of failures goes from „nearly certain“ for rank 1 to „nearly uncertain“ for value 10. The frequency range has values from rank 1 „little - failure is implausible“ for a value less than 10^{-9} to „very high: Failures in very short cycle which are not avoidable“ for a value more than $8 \cdot 10^{-3}$ per year for rank 10 [3].

Some failure of mechanical components could, due to deterioration over time, become causes of severe

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failure. "Failure mode" is defined according to EN 50126 as: "The predicted or observed results of a failure cause on a stated item in relation to the operating conditions at the time of the failure" [3]. That means that the observed object can no longer perform the function and afforded the operating conditions. Therefore, the quality deteriorating of the component does not mean failure at the same time. During the analysis, some failures become failure root causes [3] forming failure cascades (Fig.1), so a separate assessment is performed for each cause to determine its risk.

Risk evaluation is the assessment of the obtained RPN with the limited RPN value, defined in the risk analysis process, to identify the criticality level with increased risk. If the calculated RPN is above the set limit value, it is considered unacceptable and improvement measures must be implemented. If the RPN is below the set limit value, but it is not negligible, it is considered conditionally acceptable and only economically justified measures, so-called ALARP measures (As Low As Reasonably Practical) are applied [4].

For the coupling system of freight wagons in railway operator "Srbija Cargo", consisting of screw coupling and draw gear, quantitative values of failure can be obtained, based on Reports on accidents and incidents in „Serbia Cargo“ [5].

For one or more components of the coupling system, due to the deterioration of their condition over time (wear, corrosion, etc.) or overload, severity could progressively increase. For example, under the action of load, the external damage of an component of the coupling system expands, and a small crack is created. Due the corrosion, damage to an component, if not properly maintained, inevitably leads to fracture and coupling failure (Fig.1). Fishbone diagram of train break apart identify the root cause of coupling failure (Fig.2) [6].

The rank of severity (S), detectability (D) and frequency (F) have values between 1 and 10, so the risk evolution in RPN range from 1 to 1000. An overview of risk evolution according to the FMECA is given in table 1 [6].

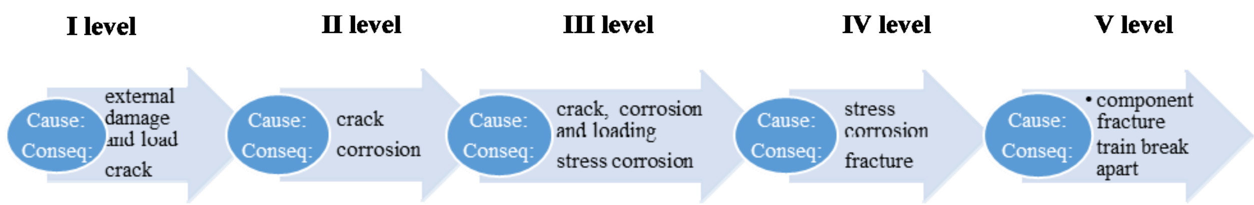

Fig.1. Progressive change of consequences and causes of coupling system components failures

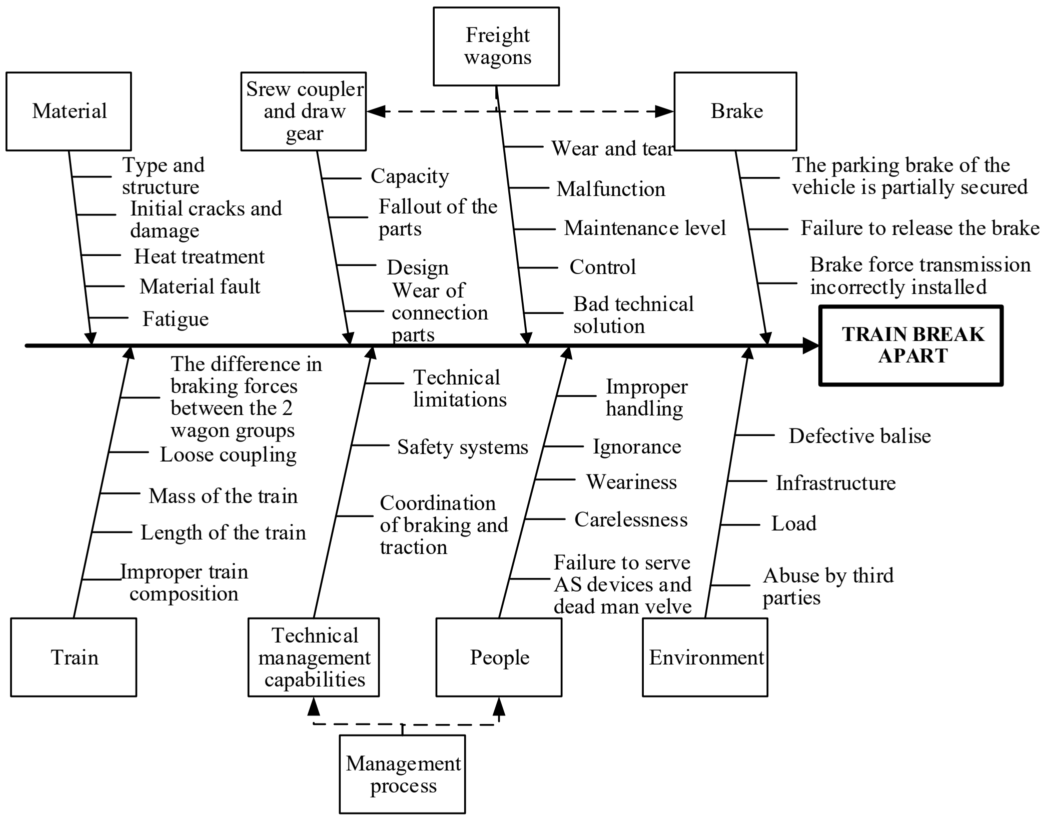

Fig.2. Fishbone diagram of train break apart

FMECA application on systems in operation that have operational data, never applied due to numerous conditions and parameters, that needs assessment, and may never occur in operation. Risk analysis by FMECA for coupling systems in operation would be very long and extensive. Using experience and data from an operation, taking into account the worst outcome in the failure chain for all components, the result is always coupling failure leading to trains breaking apart. Thus, the risk analysis was significantly cut by assessment of component failures (fractures) only. Results of risk analysis of coupling system of "Srbija Cargo" freight wagons were based on the number, equipment and technical condition of the vehicles in use in 2018-2020.

Tab.1. Risk analysis of coupling system

Component	Failure root cause	Failure	Severity (S)	Detectability (D)	Frequency (F)	Risk Priority Number (RPN)
Shackle	overload, corrosion, initial crack, material fatigue	fracture	4	6	8	192
Coupling links			4	8	9	288
Pin			4	8	1	32
Trunnion nut (shackle fitting)			4	8	1	32
Trunnion nut (link fitting)			4	9	1	36
Screw			4	9	8	288
Split pin	loosening, initial crack, fallout	fallout	4	8	1	32
Draw hook	overload, corrosion, initial crack, material fatigue	fracture	4	8	10	320
Joint pin			4	8	9	288
Drawbar			4	10	10	400
Bolt and nut (joint pin)			4	10	1	40
Nut (drawbar)			4	10	1	40
Elastic device	overload, initial crack, material fatigue	fracture	4	10	7	280
Coupling head and hose	external damage, tire aging	damage	4	8	8	256
Angle cock	external damage	fracture	4	8	6	192
Brake pipe	external damage, loosening of the joint	damage	4	8	8	256

The analysis of the risk of coupling failure showed that the RPN is the highest for component failure with the consequence of the train breaking apart. As the severity for all component failures is equal, the RPN depends on detectability and frequency. The application of the EN 50126 series standard set limited RPN value at 250 [3] and that was used in this analysis as well. The most critical component failures were [6]:

- drawbar, RPN = 400, due to the high frequency and low detectability in operation (inaccessible in preventive maintenance in operation),
- draw hook, RPN = 320, also due to the high frequency and low detectability in operation (inaccessible),
- coupling links, screw and joint pin, RPN = 288, lower risk of fracture due to lower frequency and better detectability in operation (accessible for inspection),
- elastic device, RPN = 280, lower frequency failure and low detectability in operation (inaccessible),
- coupling head and hose and brake pipe, RPN = 256, lower frequency failure and better detectability in operation.

3. APPLICATION OF DATA FROM OPERATION

The relative indicator of train breaks apart in railway freight traffic is the ratio of the number of train breaks and the traffic volume shown in millions of tonne-kilometre. This relative indicator represents the frequency of train breaks apart reduced to ton-km per year. Based on the determined frequency of train breaks apart and their effects on railway traffic in recent years, it was possible to predict the risk of train breaks accordingly. The prediction was based on data obtained for equal or similar:

- types of vehicles (wagons and engines) and their condition (quality and maintenance),
- traffic condition,
- train driving and
- external and other conditions in operation.

Limitation of train breaks apart predictions are assig data for particular railway vehicles, traffic, etc., that can not be applied on other railways. If any of the listed parameters change, the projection will not correspond to the achieved data. An example of the proposed prediction was made for train breaks apart of the operator "Srbija Cargo" in the year 2020, based on the frequency of train breaks apart from 2016 to 2019.

The frequency of train breaks apart reduced to ton-km per year for the period 2016-2019. in the freight traffic of the operator "Srbija Cargo" amounts to 0,0079 breaks/mil. ton-km per year (Fig.3). For the projected or, in our case, realized volume of 4,178 million ton-km freight traffic of "Srbija Cargo" in 2020, we can expect 33 cases of train breaks apart. However, in 2020, were only 24 cases of train breaks apart. The reduction of train breaks number as much as 36,8% compared to the previous years is not unforeseen, when it's known that decreasing trend is almost 27,5% for all accidents and incidents from 2010 [6]. This decrease in the number of trains breaking apart and the total number of accidents and incidents is significant, as it is clear that it is not an effect of the decrease in traffic volume, which amounts to only 8,5% in 2020 compared to 2019 (Fig.3). Based on presented data, it is the evident influence of new impact factor.

Within the safety management system of the railway operator "Srbija Cargo" the Accident and incident analysis team was formed at the end of 2019. The team was aim to re-analyzing all accidents and incidents after submitting the final investigation reports. The team for the analysis of accidents and incidents in which the vehicles of "Serbia Cargo" participated, as a result of their work, propose improvement measures for increasing traffic safety. The establishment of an Accident and incident analysis team resulted in greater responsibility for all involved in the railway traffic operation. A decrease in the total number of accidents and incidents, and therefore train breaks apart, have an effect due to the implementation of measures and security recommendations of the Accident and incident analysis team and the entire security management system.

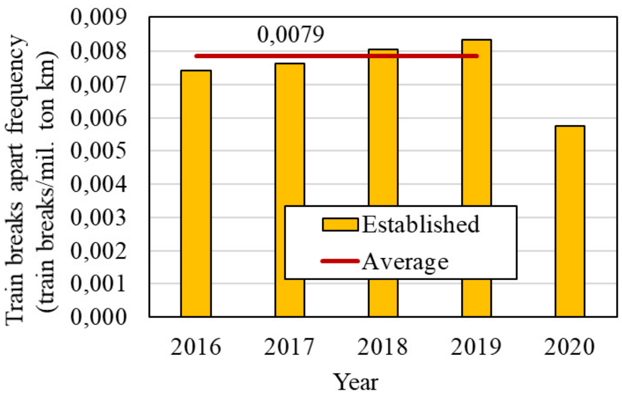

Fig.3. Frequency of train break apart from 2016 to 2020

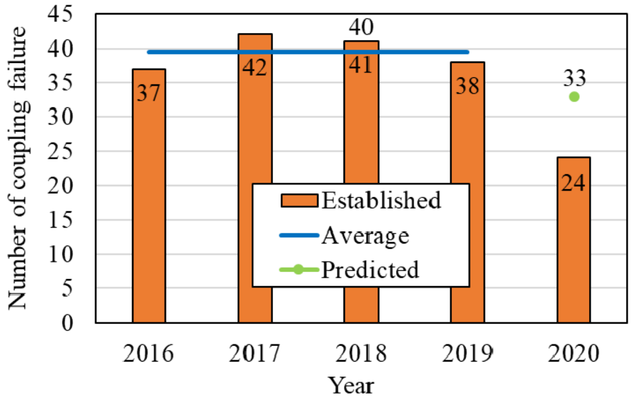

Fig.4. Prediction of train break apart number

4. CONCLUSION

To increase the safety of railway traffic according to the Regulations [7], monitoring and analysis of common safety indicators (CSI) are performed. Based on the analysis, a report is made which, in addition to the data on the CSI, contains the results of safety analysis and recommendations for improving the safety of railway traffic based on safety measures adopted as a result of previous accidents. Risk assessment should be performed by the railway infrastructure management or railway undertakers and through the review of changes in the railway network and analysis of railway safety in the previous period and the need to implement measures to reduce risk.

The cause of the train breaking apart is coupling failure, usually as a result of superposing several negative aspects. Although separated parts of the train are automatically breaked, it could lead to an increase in stopping distance, passing through a signal or crossing, and to a serious accident. Therefore, the relatively low severity of the consequences of coupling failure in everyday practice shouldn't be a reason not to take all measures to reduce them. Taking measures to reduce or eliminate the causes of coupling failure is to manage the risk of the train breaking apart usually by preventive maintenance, quality, design and operation.

ACKNOWLEDGEMENT

The research work is done thanks to the management of the railway operator "Serbia Cargo" which provided access and insight into train coupling failure cases.

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XX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
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DEVELOPMENT OF DEVICES FOR MAINTANANCE OF RAILWAY VEHICLES

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Abstract *– Maintenance in railway industry is important for proper functioning of railway system. Therefore, some measures are introduced for diagnose possible problems on time and to prevent or reduce risk of failures and breakdowns. Most important of which are inspections of individual subsystems of railway system. Product development process from idea to the final product is important for developing new products or improve today's products by using newest technology solutions that can increase quality and speed of inspection especially with the principles of IoT. In this paper is presented an innovative solution for easier maintenance of railway vehicles.*

Keywords –maintenance, railway, vehicle, wheel, inspection.

1. INTRODUCTION

Control inspections are integral part of the regular maintenance of railway vehicles and they are carried periodically with the aim of diagnosing the condition of the vehicle and its components and acting preventively in order to prevent or postpone failures.

The periodic inspection of a railway vehicle is a set of works on a railway vehicle that are carried out after a certain number of kilometers traveled or the expiration of a certain period of time of use of the railway vehicle. According to the established description of the works and the appropriate technological procedure in order to check the general condition of the vehicle, check the condition of systems, devices, assemblies and parts, replacement or replenishment of lubricants or other consumables, as well as elimination of defects on the railway vehicle.

With development of new technologies and with their wider use there is a need to implement them in IoT systems in order to process data more convenient.

In this paper is presented how new technologies can help with inspection of railway vehicles in such manner that it can improve safety and reduce operating cost of a railway vehicle.

1.1. Maintenance of railway vehicles

The Rulebook on the maintenance of railway vehicles defines the general principals of maintenance of railway vehicles. Every country that has railway service has one, in general this rulebooks are similar, and this rules can be applied whole railway systems in general. According to the rulebook on maintenance of railway vehicles, regular maintenance, which is carried periodically and planned in advance, includes:

- Control,
- Service inspections of tracting stock,
- Periodic inspections,
- Regular repairs,
- Washing and cleaning,
- Disinfection, disinsection and pest control. [1]

The parts of railway vehicles that are important for the safe operation of railway traffic, in the sense of this rulebook, are:

- brake devices and their parts (brakes);
- wheelset;
- buffing and draw gear;
- bogie;
- frame;
- suspension;
- lighting devices and sirens;
- driver safety devices;
- the locomotive part of the radio-dispatching device;
- locomotive part of the autostop device;
- speedometer and recording devices;
- pressure vessels;

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- device for automatic door closing of motor trains and passenger cars;
- high-voltage electrical devices and protective earthing. [1]

The person in charge of maintenance creates and maintains a maintenance file for each vehicle he is in charge of. The preparation of the maintenance file is based on the initial technical documentation, which is prepared by the manufacturer of the railway vehicle and which is attached to the request for issuing a license for the use of the railway vehicle.

The owner of the railway vehicle submits complete and correct technical documentation to the person in charge of maintenance.

1.2. Maintenance of axle assemblies

The correctness of the axle assemblies is checked when checking the correctness of the railway vehicle during operation and as part of regular maintenance work.

When checking the correctness of the railway vehicle during exploitation, the following are visually checked:

- wheel rim wear;
- wheel tyre wear;
- wear of the rolling surface and its eventual damage;
- rigidity of the wheel rims;
- existence of possible damage to the wheel plate, wheel band and wheel rim;
- existence of possible places of thermal overload of the wheel.

During periodic inspections, in addition to the above, the profile is also measured.

1.3. Maintenance of suspension and suspension elements

Maintenance of suspension and suspension elements is carried out in such a way as to ensure the necessary relative movements between the connected parts.

The suspension and suspension elements are maintained at every periodic inspection, and in doing so, it is checked whether there are: cracks, mechanical damage, pinching, wear, damage to the elements to protect against dust and other mechanical impurities, whether the distance between the suspension parts is within the prescribed limits.

2. OVERVIEW OF MODERN MEASURING DEVICES

In order to achieve more efficient maintenance, numerous detection systems have been developed that can be installed in the vehicle or placed near the track in order to determine potential failures during the exploitation of the vehicle and plan interventions in the period when the vehicle is out of traffic. This was made possible by modern diagnostic systems such as optical cameras, thermal imaging cameras, laser measuring systems, etc.

To assess the condition of the wheels and their life span, it is important to control the condition of the rolling surface of the wheel, the profile of the wheel rim, as well as the stress and cracks of the wheel.

In order to make control inspections in depots more successful and to be completed in a shorter time, specific diagnostic systems were developed. The main goal is to use these devices to ensure efficient diagnosis of defects, i.e. faulty parts, and spend little time for that.

Examples of such devices are shown in Figures 1 and 2. They are made by company Goldschmidt.

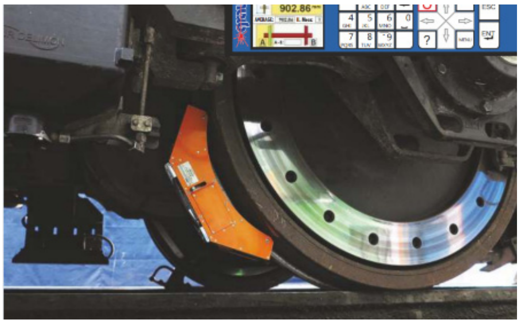

Fig. 1. Measuring wheel diameter in three points [2]

Fig. 2. Measuring the geometric parameters of the wheel rim [3]

3. IMPROVEMENT OF CONTROL INSPECTIONS

3.1. Laser wheel profile control device

The profile of the wheel rim determined by the standard UIC 510-2 allows the vehicle to move on rails and has the greatest impact on the safety of movement, the smoothness of the vehicle, the wear of wheels and rails, etc. During the daily movement of the vehicle on the rails, wear and tear and changes occur on the tread surface of the wheel. If a visual inspection reveals that there are some damages that could threaten the geometric characteristics, the rim profile of the wheel is measured, namely: rim height, rim thickness and rim sharpness. The sharpness of the wheel rim is measured with a special device, which is called a universal qR meter (Fig 3). [4] [5]

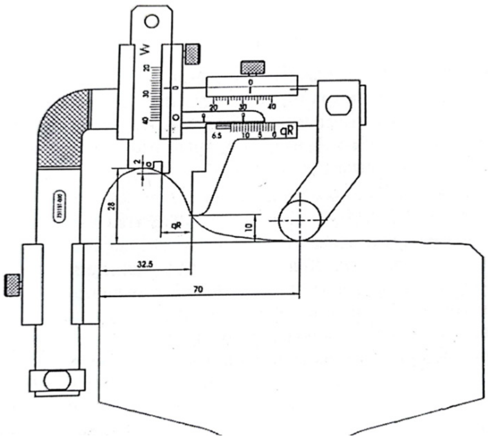

Fig. 3. Universal qR measuring device [4]

However, determining the qR measure is also possible with a laser device. By scanning the profile of the wheel rim by using the laser profilometer, the coordinates of the points of the profile of the wheel rim are obtained (Figure 4). By processing the obtained data, a standard qR measure is obtained for the scanned rim of the wheel.

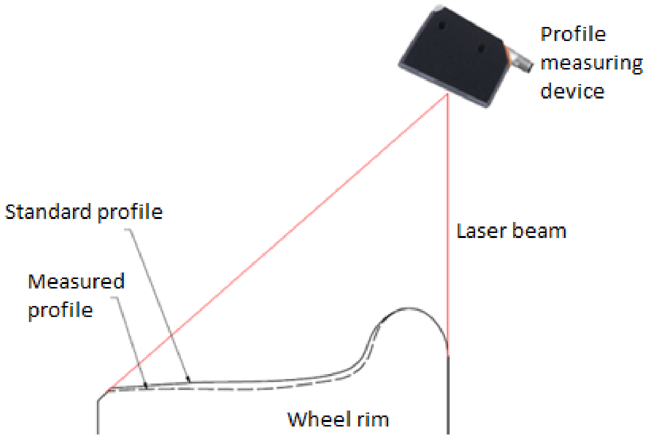

Fig. 4. Scanning the profile of the wheel rim

Obtaining the qR measure based on the scanned points of the wheel rim profile is done as follows:

For the sake of easier comparison of the results, the coordinate system is set as when measuring with a universal qR meter (Figure 5).

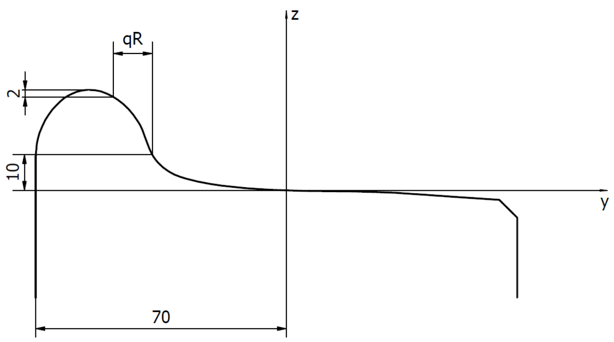

Fig. 5. Obtaining a qR measurement using a laser profilometer

The center of the y-z coordinate system is placed 70 mm from the outer edge of the wheel rim, and on the surface of the wheel. By lowering by 2 mm in the z direction from the position of the highest point and reading the corresponding y coordinate for that displacement, the first point reading of the qR measurement is obtained. By moving 10 mm in the z direction from the coordinate origin and finding the y coordinate on the rim profile, a second point for reading the qR measurement is obtained. The absolute difference of the y coordinates of those two points is the required qR measure (Figure 5).

In order for the wheel rim to be correct for exploitation the measured measurement qR of the wheel rim should be greater than 6.5 mm, while the outer surface of the rim must not have ridges larger than 2 mm, and the surface of the rim covered by the measurement qR must not have sharp edges and channels. [4]

Based on the research of laser devices for measuring the distance of machine components, the concept of a device for measuring the qR measurement of the wheel rim was determined.

The basic component that should be in the device is the IFM OPD 100 laser. In addition to the laser device, there should be an IO link inside the device that enables communication between the laser and adequate hardware, which will contain the appropriate software for data processing. This hardware device - an Arduino or Raspberry Pi device must be equipped with Wi-Fi in order to have a wireless connection with the computer where the data would be stored. The device must also have a power source in order for the device's components to work properly and to achieve proper autonomy in operation as well as easy charging with electricity.

Inside the housing (Figure 6) there should be neodymium magnets at the appropriate position and distance to facilitate the positioning of the device on the wheel. The housing must be positioned in such a way that when approached from the side, the housing is positioned and the correct main function of the product is enabled, which is that the laser emits the beam at an appropriate angle suitable for further processing. Also, the magnets should allow easy removal of the product by pulling it away from the wheel.

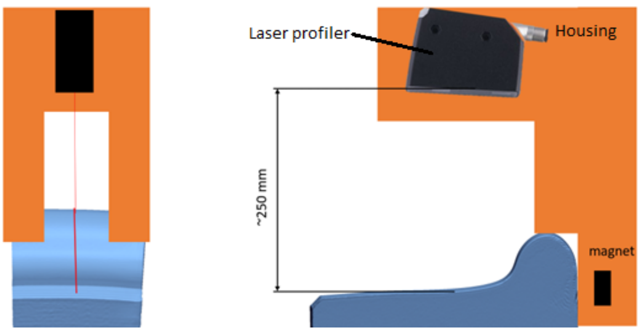

Fig. 6. Sketch of a prototype device for measuring the profile of a railway wheel

3.2. Measuring the diameter of a wheel on a vehicle

Railway vehicles have steel wheels, which roll on a steel track (rails) and wear out during operation. That wear is uneven and can change the profile of the wheel rim, as well as the diameter of the wheel. After a certain period of exploitation, when certain parameters of the wheel geometry reach minimum values, it is necessary to process the rim of the wheel. As part of the constant monitoring of railway vehicles, the profile of the wheel rim is checked, but it is also necessary to periodically check the diameters of the wheels. Discrepancies in the diameter of the wheels on one axle can cause additional slippage and accelerated wear and can endanger the stability of the vehicle's movement and traffic safety.

Wheel diameter measurements with a standard on-site gauge can be performed when the axle assembly is disassembled from the vehicle, i.e. base, which is most often done when the rail vehicle is being overhauled. However, measuring the wheel diameter when the vehicle is completely assembled is not possible with standard gauges due to access. That is why the wheel diameter is measured in three points.

The device for measuring the diameter of a wheel in three points works on the principle of obtaining coordinates for three points located on the wheel itself. The coordinate system itself and its position is not so crucial for obtaining the diameter, but accuracy is required when measuring. Small deviations when measuring the positions of these points can cause large deviations in the final measured diameter. Therefore, the design of the device would be such as to introduce as few initial errors as possible. This would be achieved by fixing two points on the device itself and their exact positions would be known, while the third point would have a change in one direction, while it would be fixed in the other. That change of position needs to be determined by a high-precision displacement sensor. Such a device would give good enough results in measuring the diameter itself, the measurement error would be less than 3%.

The following is a description of the mathematical model for measuring the diameter of a wheel at three points. If there are three points located on the diameter of the circle ***(x1, y1)***, ***(x2, y2)***, and ***(x3, y3)*** and the function of the circle in explicit form:

$$x^2 + y^2 + 2gx + 2fy + c = 0 \qquad (1)$$

Each of these coordinates must satisfy the circle function. By substituting the coordinates ***(x1, y1), (x2, y2), and (x3, y3)*** in the equation of the circle, three equations are obtained that are solved to obtain the constants g, f, c. From the obtained constants, the diameter of the circle is found as:

$$d = 2 \cdot \sqrt{g^2 + f^2 - c} \qquad (2)$$

Considering the presented mathematical model of measuring the diameter of a circle in three points, the concept of the device was established. The device is designed around a high-precision displacement sensor with accompanying electronics. A microcontroller (Raspberry Pi) with a touch screen that would process data and save it, as well as a power source (battery). The equipment would be installed in the device housing, which would ensure safe and accurate use of the device. A concept sketch of the device is in Fig. 7.

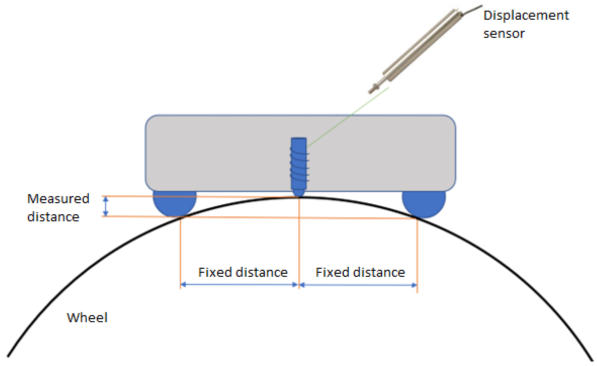

Fig. 7. Sketch of a wheel diameter measuring device

4. CONCLUSION

This paper presented solutions for easier inspection and maintenance of a railway vehicle. These solutions can be implemented in already existing systems and improve them. All data that is measured can be stored on a cloud and accessed over the Internet from anywhere in the world. In that manner these presented technologies can be easily implemented in Industry 4.0 with aim to help with control inspections of a railway vehicle. By implementing these technologies in Industry 4.0 we can expect that safety and reliability of rail vehicles will improve. With easier inspections of certain components, inspectors will save time for inspection, and that time can be used inspecting more critical components of a rail vehicle.

ACKNOWLEDGEMENT

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DIGITAL TWIN IN RAILWAY APPLICATIONS

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Abstract *– The railway is a huge system with several subsystems, and in recent years, with its modernization and development, become even larger and more complex. Railway infrastructure and rolling stocks require attention from aspect of maintenance, monitoring and management. Digital Twin (DT) technology with implemented advanced technologies like IoT, Artificial Intelligence can respond to a large number of requests coming from the Railways. The railway provides space for the successful application of DT technology, the aspiration to digitize the railway and reduce costs, optimize the operation or to simulate any activity before it is actually physically implemented, is becoming increasingly popular precisely because reduces the time and improve the system. This paper aims to show the current application of DT in railways, what are the benefits of application, why this concept is becoming more and more interesting and attractive for Railways.*

Keywords – Maintenance, monitoring, digital trains, rail turnouts, ERPS, digital model.

1. INTRODUCTION

According to a report by market research company Grand View Research, the global digital twin market size was $7.48 billion in 2021 and is projected to grow at a compound annual growth rate (CAGR) of 39.1% from 2022 to 2030 [1]. DT is a virtual representation of a physical object that is primarily based on the exchange of data between the virtual model and the physical model. Data exchange or communication depending on the maturity of the DT and it can be in one direction, for example when the physical model sends signals and data to the digital replica, or two-way communication when the virtual replica and the physical model exchange data, in that case the full communication between the two objects physical and digital is achieved [2]. The exchange of data in real time allows to monitor of the physical model in the real state. Data collection takes place through sensors that are positioned so that they can measure values needed to track a specific physical object, process or system. By analyzing the collected data in real time through artificial intelligence or other methods, it is possible to detect certain failures or indications that they will occur in future [3].

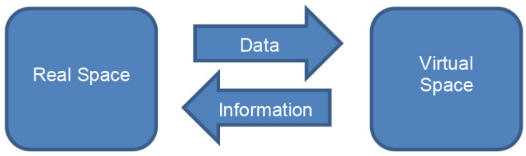

Fig.1. Information (data) exchange between Real Space and Virtual Space

In addition to artificial intelligence, the basic technologies that enable the creation of DT are Internet of Things (IoT), VR/AR, Cloud Computing, Communication (protocols, Standards, 5G and 6G networks, etc.), Hardware and Development technologies [2]. The application of DT technology in industries is increasing, the reason for this is the advantages that DT technology brings, the purpose of application is reflected in the possibility of optimization, quick and easy decision-making, remote access, real-time monitoring, security and maintenance of certain processes, systems or objects. Industries which application successfully DT are: Aerospace, Manufacturing, Healthcare, Energy, Automotive, Petroleum, Public sector, Mining, Marine, and Agricultural [4]. According to Thomas M., predictive maintenance also requires a strategy

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that would consider the Railway system as a whole, that is, connecting all data from individual components in the Railway system, this indicates the need to use Digital twin technology [5]. The aim of writing this paper is to give an overview of the current application of DT technology in Railways. Examples of successful applications of DT technology in railways are given, the examples show the benefits of the digitalization of the Railways.

2. APPLICATION

The company Siemens Mobility has developed the Railigent mobility program package that enables a holistic approach for the Railway System, covering the entire value chain, from data transmission to their analysis and feedback. It enables monitoring, diagnostics and improvement of railway assets. The driver of this software package is MindSphere, an IoT operating system from Siemens [6]. The Railigent program package is designed to include the infrastructure and vehicles (rolling stock) of the railway. By collecting data and properly analyzing it, it is possible to ensure maintenance and increase operability. The challenges that Railigent faces are the large amount of data collected, the synchronization of data collected with vehicles (wheel profile condition, braking behavior) and track data (track damage) [6].

The development of smart algorithms for data processing supported by sensors, enable smart diagnostics that can detect any anomaly or error on the bogie and assess the condition of the bogie itself. Intelligent Diagnostics aims to show behavior in real time and possible changes to bogie due to dynamic influence. By monitoring and analyzing the measured signals obtained from the sensors on the bogie, maintenance can be significantly affected, by predicting the time for the replacement of individual components on the bogie through the analytical model, and detecting possible malfunctions [5-6].

2.1. Railway bridges

Researchers from Cambridge University in collaboration with partners Network Rail, Microsoft and The Alan Turing Institute are jointly developing a system for monitoring the condition of bridges in Great Britain. Many bridges are old and near the end of their designed service life, for these reasons they represent a critical structure in the Railway infrastructure that needs to be monitored and controlled. By applying advanced BIM modeling, the finite element method, real-time data analytics and a combination of different sensors for measuring physical quantities from which a large amount of data is obtained (Fig. 2), it is possible to create a DT of bridges based on physics and real measured data through sensors for carrying out structural analysis and carrying capacity assessment bridges [7].

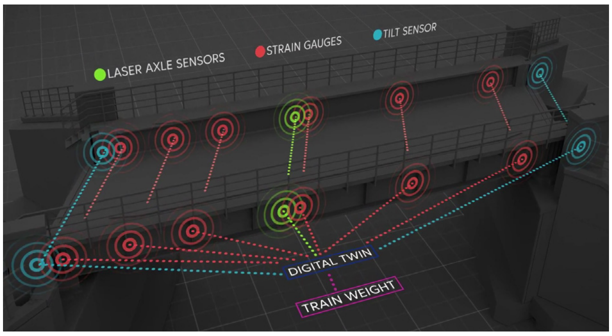

Fig.2. Information (data) exchange between Real Space and Virtual Space [7]

Based on the sensors and algorithms of the system and the deformation response of the moving train (Fig. 3), it possible to predict the axle weight of the passing train. The collection of these data enables the control of overloading, stresses and deformations in the structure of the bridge. With a sufficient amount of data is useful for generating an accurate digital representation of the bridge structure. By analyzing the structure of bridges throughout their entire life cycle, it provides engineers with useful information for planning safety and proactive maintenance programs and optimizing future design [7].

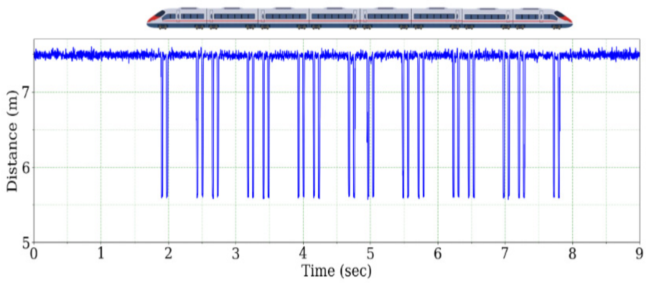

Fig.3. Deformation response of the bridge [7]

2.2. Digital Trains

The company Digital Virtual Reality Systems has developed Digital Trains that brings together the Digital Twin of individual elements, including dynamic simulations that correlate with test results. Simulations include: Route profile and tracking, static and dynamic measurement, track quality assessment, dynamic simulations with rail-to-wheel contact, derailment and collision research as well as consumption [8].

Digital Trains can be used to design collision energy management systems, understand vehicle performance under normal vehicle operating conditions, and how the train connects to the rail infrastructure. DT and simulation results are easily shared with others, making this an effective collaboration tool for project management, training operators and products to visualize, understand and optimize performance [8].

Fig.4. Digital Train Software [8]

2.3. Rail Turnouts

Railway Turnouts (RT) are critical points on the railway infrastructure. In cases of simultaneous occurrence of high or low values of the periodic mean temperature and close to zero value of the second temperature difference indicator, there is a probability of failure. Failure is the possibility of cracking (which can penetrate deep into the rail and lead to its breakage) or buckling of the track. From this reason, need to ensure the correct technical condition of RT and their components requires certain measurements and data collection on the temperature change between the temperature in the rails and the stress-free temperature (SFT). The system for measuring temperature differences in real time and visualization enables the application of DT for monitoring the condition of RT from those aspects. The system for measuring rail temperature differences is shown in Figure 6 and includes the components UbiBot WS1 WIFI wireless temperature logger and external DS18B20 temperature sensor integrated into an S49 (49E1) type rail as Tszyn WS1 WIFI [9].

Fig.5. Measuring station Tszyn WS1 WIFI with rail type S49 (49E1) [9]

The method is based on measuring the internal head temperature of the S49 (49E1) rail using the UbiBot VS1 WIFI wireless temperature, humidity and light recorder equipped with an external DS18B20 temperature sensor integrated into the S49 (49E1) type rail. The measuring station provides data on the ambient temperature, humidity and ambient light [9].

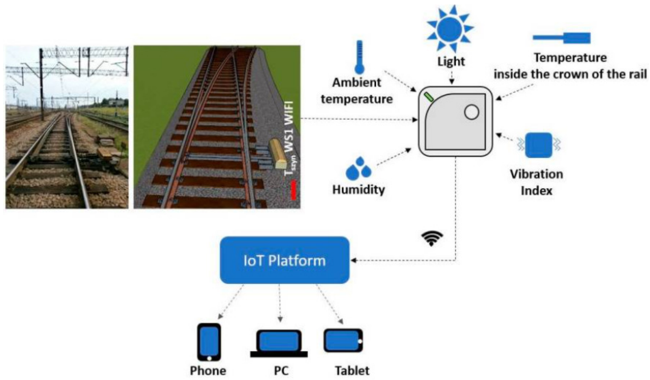

Fig.6. Measuring system with IoT Platform on RT [9]

2.4. Electric Railway Power Systems

DT technology is successfully adopting for highly complex Electric Railway Power Systems (ERPS). The DT technology concept for ERPS adopted can be seen of Fig 7. The application of DT and the development of various simulators gives importance, especially when it comes to monitoring the main circuit of the Railway System, from the aspect of current and voltage at certain points. On the other hand, the ability to see not only one problem, but the entire system, makes the DT technology more attractive.

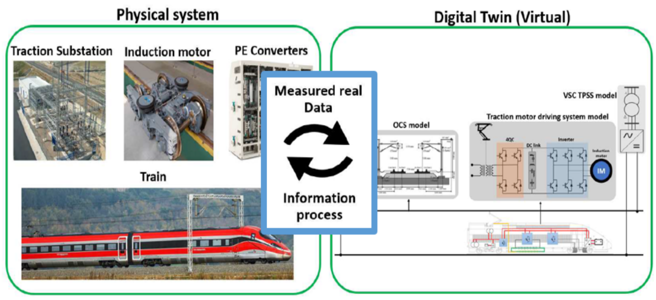

Fig.7. ERPS representation of a physical system in a digital twin [10]

Implementation of Digital Twin (DT) can ensure the correct operation of monitoring and control function. The main application of DT in this area is [10]:

1. *Energy management*, ERPS is huge and complicated high-power network, connection between renewable energy source and energy storage system, make energy control system more complex. This communication between different layers can be implemented by the Internet of Things (IoT) using DT technology.
2. *Power flow analysis,* analysis of energy flow in various parts of the network and sending feedback, application of DT for power flow optimization is required.
3. *Fault diagnosis and maintenance,* The railway has

multiple systems that have their own control part, different types of sensors that are exposed to mechanical vibrations and electromagnetic interference. By applying offline simulation, it can help determine faults and errors in systems. The DT concept represents an ideal platform for such a purpose.

4. *Condition monitoring* aims to provide prediction of any destruction of electrical equipment, fault diagnosis and maintenance on ERPS infrastructure.
5. *Timetable management and Operating profile optimization.* Using DT in real time enables an accurate timetable, better planning and monitoring of railway traffic. Optimization of the operating profile aims to reduce energy consumption and increase system efficiency.

3. BENEFITS

With the development of computational resources and the increase of data storage and the development of communication technologies together with the application of Artificial Intelligence, it is possible to create a DT that would create a strong connection between a digital and a physical object [11].

The benefits obtained through the connection enable a more precise visibility of the system's functionality. With such a real-time connection, it is possible to optimize and reduce system errors, predict future failures and anomalies based on collected and analyzed data. The possibility of monitoring the life cycle of a certain system can monitor the behavior of the system in operation and detect failure patterns, which significantly contributes to the improvement of the design, functionality and reliability of the system. DT technology enables interaction between systems, and the ability to make decisions based on current data.

4. CONCLUSION

The DT concept requires to have knowledge about the physical behavior of the system, with the sensors in the right place and collecting data it is possible analyze the observed system. DT realistically shows the current state of the system based on measured values by sensors and actuators that have in order.

The potential of DT technology is mainly in the holistic view of a complex system, more precisely in connecting several sub-systems into one final one. In this way, simple monitoring of all subsystems, effective optimization and predictive maintenance can be achieved, which can be important in the Railways for DT to constantly refresh the collected data. On the other hand, creating a DT for a holistic approach also means investing more energy and effort in realizing the DT and its application. In this paper, examples of DT on certain sub-systems in the Railways are given. We can notice that the applied models are very simplified and are oriented towards the critical points in the systems. Future directions of research would be towards the creation of complex DT models in the Railways that would have a full holistic view of the system. A problem which is also interesting for research is the synchronization of physical and digital model data that are exchanged.

ACKNOWLEDGEMENT

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RAILWAY INFRASTRUCTURE MONITORING USING CLASSICAL COMPUTER VISION AND CONVOLUTIONAL NEURAL NETWORKS

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Milan BANIĆ[3]
Sergiu-Dan STAN[4]

Abstract *– The introduction of classical computer vision (CV) and artificial intelligence (AI) into modern transport systems has been gaining momentum for some time and is becoming increasingly prevalent, both in road and rail transport. The influence of artificial intelligence in modern vehicles is mainly related to a certain degree of autonomous driving, however, it can have many other applications. This paper describes the application of artificial intelligence to monitor and maintain railway infrastructure. By applying the above-mentioned technology approach, it is possible for the train to "see and be aware" of the railway infrastructure overhead system - contact line masts, as well as contact wires and catenary wires. The reliability of the detection system exceeds values of 99% when it comes to the detection of contact line mast, while the detection of the wires is done by classical computer vision. For training such a system, a dataset of 500 images was used. The dataset images were mostly taken on the routes of the Serbian Railway in different weather conditions, including the extraction of frames from high-resolution videos recorded by cameras installed at the front of the train. Also, part of the images was taken at night, with an infrared camera.*

Keywords – railway, computer vision (CV), convolutional neural networks (CNNs), railway overhead system, on-board maintenance.

1. INTRODUCTION

The railway represents one of the most economical, most comfortable, fastest, and, above all, safest forms of efficient transportation. In the era of constant technological improvements, demands for ever greater power, reliability, and transport capacity iterate and improve already developed railway systems. With the gradual introduction of artificial intelligence, the technical complexity of these systems acquires a new dimension. However, railway vehicles and infrastructure need to achieve a longer life span and reliability and thus meet the criteria and standards, adequate supervision and maintenance must be carried out constantly.

The system for monitoring the condition of the overhead railway system is essentially a software system, which is a subsystem of a wider holistic approach [1] that is being developed for the purposes of the Smart 2 project [2]. The way it works, among other things, is based on the integration of classical computer vision (canny edge detection and Hough transform) and convolutional neural networks (CNN) into a common system. The mentioned holistic system also contains a subsystem for rail track and signal detection, described in [1]. The metric method used for validation were intersection over union (IoU), average precision, and recall. The obtained value of IoU applied on the entire validation dataset exceeds 0.7. Calculated values of average precision and recall were 0.89 and 0.76, respectively. The paper [3] deals with maintenance in the area of railway and describes the new concept of train and railway infrastructure maintenance. Railway condition monitoring and on-board diagnostic systems are particularly highlighted in the paper. On-board diagnostics using digital image processing were performed to monitor the condition

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of the pantograph. A thermal camera was also used to conduct the experiment. The paper [4] proposed the integration of a smart sensor and AI technology for predictive maintenance in the railway sector. The developed prediction algorithm was described, which aimed to predict the service life and timely replacement of wheel bearings.

The subsystem addressed in this paper allows the train to have its own intelligent vision of the environment and can be classified into on-board systems for monitoring the condition of railway infrastructure.

2. OVERHEAD RAILWAY INFRASTRUCTURE SYSTEM

The overhead system is a very important part of the railway infrastructure. This system is primarily responsible for powering the train. Its main parts are contact line masts, cantilever supports, contact lines, and catenary lines. Contact lines are in constant contact with the pantograph during train movement. Besides powering the train, the main task of these lines is to maintain straightness over time. Fixing both ends (grooved wire), as with the usual power transmission, would not give satisfactory results. The reason why this is so is that the conductor changes according to the temperature changes of the environment. In fact, sagging of the wire may occur (sagging wires are free to deform). Tightening (overtightening) should also not give satisfactory results. This practically means that the contact line should not be affected by weather conditions (high temperatures - expansion, lower temperatures - increase in brittleness and the possibility of breaking the wire). If the contact line is not straight, but wavy, the pantograph may get stuck during movement. Also, there is a possibility of sparks appearing.

Auto tensioning device including pulleys and hanging weights partially solves this challenge. The construction solution of the contact line as is shown in Figure 1 includes the established arrangement and the correct distance between the masts, as well as the catenary line supported by droppers, enabling the pantograph to fit correctly on the contact line and the power supply to be transmitted properly. If the contact line breaks, the jumpers are there to ensure correct connection and voltage distribution.

3. OVERHEAD RAILWAY INFRASTRUCTURE SYSTEM DETECTION USING CV AND CNNS

From the perspective of a camera located at the front of the train, contact and catenary lines may go straight or curved and may intersect each other at some points on the horizon. Clouds, sun, rainy weather, snow, and other influencing factors may affect the accuracy of detection and should also be considered. This chapter will address the topic of the application of CV, including image processing, for the purpose of more accurate detection of the overhead system. Edge detection and Hough transformation are two subunits that make up the computer vision process applied in this paper. It was necessary to perform several operations on the images to implement edge detection algorithms to find the lines of the overhead railway system. The entire process is applied to images, videos, and in real-time. The input form for further processing was images, which were imported into the future algorithm. The input image format was .jpg format. Based on the input, the program returned multidimensional matrices. The numerical values that were in the matrices represented the value of the pixels belonging to the loaded data. Based on that, it can be said that the image is a matrix of light, where the intensity represents the value of the pixels in the cell of the matrix. Since grayscale images have only one channel (from black to white), processing them is much more efficient than processing color images directly. For this reason, the images were first converted from RGB (red, green, blue) to grayscale[1].

The Gaussian filter serves for averaging the intensity of the pixels in the image [1]. This approach removes noise and reduces the possibility of false edges being created. The process is done by gradually passing the filter through the entire image. The size of the filter is 5x5. Image smoothed in this way is ready for further transformations, even though this process

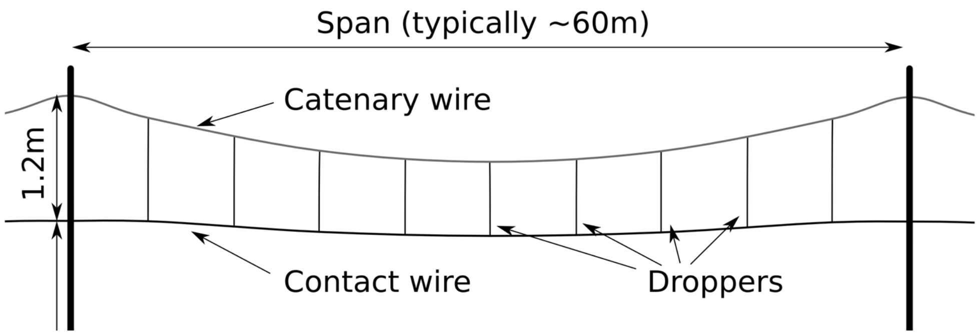

Fig.1. Overhead railway system [5]

can be considered optional due to canny edge detection itself already containing a noise reduction tool.

Figure 2 shows an image that will be used throughout the paper as a relevant example of the condition of the railway infrastructure. Rails, contact masts, and contact lines, among other things, can be seen in the image shown. In the specific case, the image was passed through the first two steps - RGB to grayscale and filtering.

Fig.2. Grayscale and blurred image

Contact/catenary lines represent a distinct change in lighting when viewing the entire image. Due to the mentioned change in lighting, the multi-step canny edge method has become the first choice for the detection of objects of interest. The dimensions of the input images were 1920 x 1080 pixels. The number of channels (in terms of color) was one. Mathematically, a canny edge can be defined as follows:

$$\text{derivative}(f(x, y)) \tag{1}$$

Figure 3 shows the applied canny edge detection algorithm, where all sharp edge changes in the image are drawn with white lines on a black background. The canny algorithm was applied to an image previously converted from RGB to grayscale and then blurred.

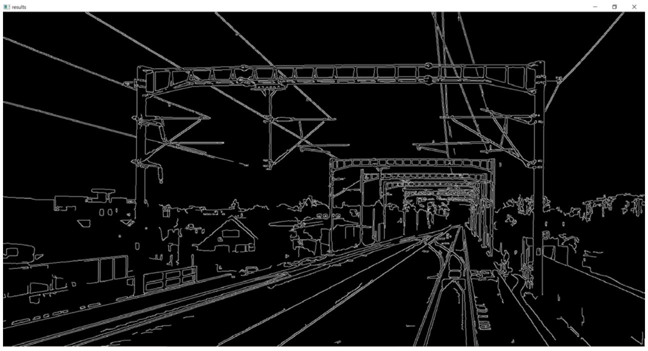

Fig.3. Canny edge detection applied on the processed image

Depending on whether it is a small or large derivative, it indicates whether it is a small or large change in the intensity of light. By comparing Figures 2 and 3, it can be concluded that the edges are separated wherever the elements cross. Canny implements the derivative in both directions (x and y). This calculates the gradient over the entire image, also in both directions. The white lines (contains from a series of white pixels) in Figure 3 show the strongest gradient. The gradient upper threshold defined (in this case 150) decides what will be plotted [1]. The lower threshold was 50 and the edges that were below this defined threshold were not plotted. As for the values between the thresholds, if the region is directly related to parts with high intensity, they would be accepted. If not, they are simply not plotted (refers to values between 50 and 150). There are no unique values that must be taken as lower and upper thresholds, but only indicative recommendations. Each example may specifically require setting these values. This is considered a routine part of creating an algorithm.

However, since there are elements in the image that are not required for detection, by applying the ROI (region of interest), it is possible to let the algorithm know which part of the image should be considered and which should be ignored. The next step is the transition to the binary domain, i.e. the so-called masking of the image. A canny processed image only has values 0 and 255, so it can be relatively easily converted to a binary value. It is necessary to blend the canny image and the masked image so that only the gradient area of interest remains as a result. The condition for this to work is that all images that figure, regardless of whether they are input (raw) or processed, must have the same dimensions. By adding the pixels of the canny image and the masked image, only those with a binary value of 1 are drawn.

The next step in implementing the CV algorithm is the Hough transform. It refers to the detection of lines of interest and their highlighting in the original image. This process is carried out by building on already obtained results of image preprocessing using the Canny algorithm. The HT-Canny algorithm can detect the low-intensity edge more efficiently compared to traditional algorithms [1]. For example, Maire et al. [6] used a similar Hough transform approach to that presented in this paper for railway track detection.

The Hough transform is performed in the parametric space (m, b), unlike previous implementations, which were in the Cartesian coordinate system. This transition is done by mapping lines to points in the parametric system, as well as points to lines. The image has been divided into grids, so cells with the highest number of sections are taken as relevant, i.e. as best fit lines [1].

In Figure 4 and Figure 5, blue lines show the final result of applying classic computer vision, all line structures of interest (rails, contact lines, contact lines) are highlighted. Any interruption in detection is intended to indicate a possible problem by giving an alarm to the competent persons who are responsible for monitoring such situations. In this way, much better real-time monitoring and quick detection of possible problems, before they caused any consequences, were made possible.

Detection of contact line masts is enabled by using CNNs, more precisely YOLO v5. The convolutional neural network is trained with input images of 1920 × 1080 pixels. To save time and computer resources, the training was performed through Google Colab using a graphical processing unit (GPU). A custom dataset was used consisting of 500 relevant images. The images were labeled with objects of interest (contact line masts) for the railway environment [1].

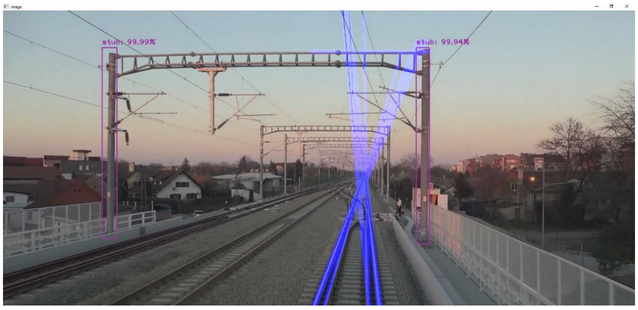

Fig.4. System for detection supported by HT-Canny and Yolo V5 algorithms [1]

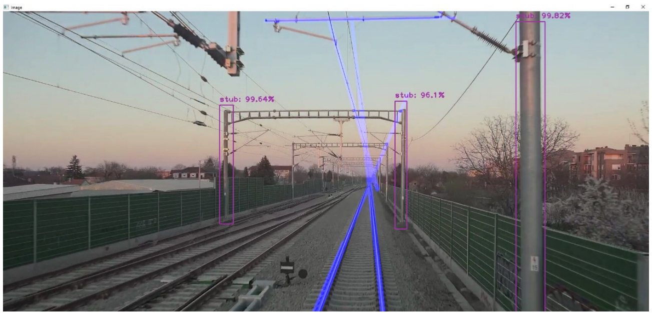

Fig.5. Detected rails, lines, and contact line masts [1]

Darknet is used as the framework of the YOLO algorithm. Its advantage is that it runs on a graphics card. CNNs are characterized by a large number of layers, unlike classic neural networks. The results are displayed with bounding boxes around the detected objects and this is followed by the name of the class and the percentage value by which the algorithm lets us know how certain it is that there is a detection belonging to the class within the bounding box. As can be seen in the figures, the percentage values for contact line masts are over 99%, which largely validates the neural network created in this way. Combining the detection system with the digital map and their comparison in real-time, a proposal for a new approach to the monitoring of railway systems aimed at the timely maintenance of the railway infrastructure is given. In this way, the developed algorithm aims to serve as a system for checking whether each element of the overhead system as well as other infrastructure elements is in its place and proper condition, and if it is not, to provide an instant warning.

4. CONCLUSION

The main goal of the research is to contribute to the area of intelligent railway infrastructure monitoring, but also to the detection of other objects of importance on the railway. Certification of such systems is the biggest challenge, considering the reliability that needs to be achieved when dealing with complex systems such as the railway. The main contribution of this paper should be the proposed system for the detection and monitoring of the railway infrastructure objects such as contact line masts, contact lines, catenary lines, and rails based on the integrated Hough–YOLO method. This system is based on the integration of traditional CV and AI into a single system of higher reliability. The current limitations of this paper relate to the size of the dataset used to train the CNNs. Further aspects of this work, in addition to the creation of a larger dataset, will go in the direction of a more detailed pairing of the developed system with a digital map and achieving even greater reliability and functionality.

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ANALYSIS OF DEFECTS ON RAILWAY TRACKS OF SERBIA ON THE SAMPLE OF TWO DIFFERENT LINES

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Abstract *– This paper discusses the current situation of the railway infrastructure of the Serbian Railways - common defects on the rails, as well as the most common defects and failures at turnouts and tracks generally. A study was also conducted on the classification of top mechanical defects on them, as well a statistical analysis of converging data that was carried out in order to determine the most common defects that occur on the railway track and consider what leads to such defects.*

Keywords – Track, Rail, Defect, Joint, Serbia

1. INTRODUCTION

Railway track is a line that connects two or more places, with equipment that serve to carry out railway traffic. The primary purpose of the track is to provide guidance to the wheels of the train and absorb the dynamic load caused by the movement of the train [1].

Overhaul or major repairs of the railway track are approached, when it is no longer possible to ensure safe rail traffic [2] with current maintenance works, by repairing malfunctions and defects.

A very common place of rail damage is at the ends of the rail when it is connected with another rail by fishplates (joint bars), as well as in the welded joints of the rails welded into a continuous welded rails (CWR). Observing rail defects, through various aspects, has been dealt by various researchers around the world. Popović *et al* [8] point out two basic types of defects on Serbian railways: defects due to contact fatigue of the rail steel when the wheels roll on the rail head, and defects caused by friction, and give closer descriptions. Moreover, Popović *et al* [3] show defects caused by friction, after which the rails must be repaired by machining and then surface welding with electrodes (which some of those they compared in their work), in order to restore the required profile of the rail head.

In this paper, all observed defects on the two lines: Niš – Dimitrovgrad – the state border with Bulgaria and Niš – Preševo – the state border with North Macedonia, which spotted by Serbian Railways staff, are analyzed.

2. DEFECTS DUE TO CONTACT FATIGUE AND FRICTION

The main factors that define rail degradation are wear and fatigue, which influence the rail become unusable due to unacceptable profiles, cracks, peeling and fractures. Despite the improvement in the quality of the steel, higher loads cause more wear and fatigue, and breakages sometimes occur after less than a year (minimum design life of the rail is 7 years).

While rail wear has been significantly reduced by the introduction of suitable steels and lubricants, defects caused by the fatigue of the rail steel when the wheels roll on the rail head, so-called RCF (Rolling-contact fatigue) faults become an increasing problem, especially on highly loaded transport lines. Fatigue fractures of railway rails, are one of the main factors of train derailment nowadays [11].

As a result of higher stresses, the local yield stress can accelerate fatigue crack initiation and growth. It should be mentioned that surface cracks are a

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relatively new problem associated with high speeds and loads. In the past, the rails were exposed to intense wear and tear, so the surface layer was constantly peeling off, and with it new cracks were developed. With the development of modern rail steels that have a much higher wear resistance, the removal of the surface layer has been reduced, so the resulting cracks need more time for further development.

2.1. Defects due to contact fatigue

All over the world, including on the rails in Serbia, there are two basic types of rail defects due to the fatigue of the rail steel when the wheels roll on the rail head (RCF - Rolling Contact Fatigue): squat defects and head checking defects [8]. Both can be repaired by welding.

Defect Head checking – HC

The HC defect is found in the form of fine short oblique surface cracks at a mostly regular distance, which is usually 1-7 mm. If the defect is not removed in time, it progresses leading to separation of smaller or larger parts of the running edge at the rail head. Within the UIC 712 standard, the defect is marked with code 2223.

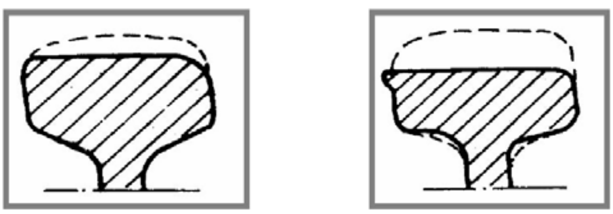
Squat type defect

This type of defect is the most common, characterized by the appearance of microcracks under the track surface. Cracks in the indentation are caused by high dynamic loading of the track from the rolling of the wheel on the rail, which leads to fatigue of the material. At first, these cracks look like a small dark spot. They then increase from the bottom of the point and grow at a shallow angle in the longitudinal direction. The defect is marked with code 227 according to UIC code 712.

2.2. Defects caused by friction

Defects caused by friction on the straights

Figure 1 shows the appearance of a typically damaged rail head away from rail ends and in rail ends of the straight line.



a) away from rail ends *b) in rail ends*

Fig. 2: Sketch of a worn rail in a bend [3]

Defects caused by friction in bends

Figure 2 shows the damage to the inner edge of the head of the outer rail, which is caused by the centrifugal force that tends to push the vehicle towards the outer side of the track, where the outer wheel flange rests on the edge of the outer rail.

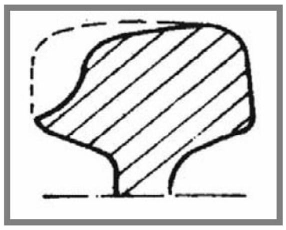


Fig. 2: Sketch of a worn rail in a bend [3]

3. MAINTENANCE OF RAILWAY TRACK

Regular track maintenance is carried out mainly at fixed intervals (periodic / regular maintenance) and consists of inspection and repair / removal of defects [5].

Rail defects can be classified into surface and deep defects.

4. DEFECTS IN RAIL WELDED JOINTS

4.1. Welded rails by the aluminothermic melting process

Aluminothermic welding can be: aluminothermic fusion welding or aluminothermic pressure welding.

Aluminothermic fusion welding is used in the formation of the CWR, which joins the ends of the rails by melting preheated liquid metal from the chemical reaction between finely divided aluminum and iron oxide [9]. Therefore, it is performed at joints, and it is mainly practiced in the field, because the equipment is easily movable. Before welding, a distance is left between the ends of the rails:

$$a = 0.75\sqrt{A}, \text{mm} \tag{1}$$

where A is the area of the rail profile in mm^2, and then the groove is filled with wax. The cavity filled with wax represents the model around which the box (mould) is placed and the casting sand is packed. After the molding is complete, the gas flame from the soldering lamp is directed through the window, melting the wax model and preheating the edges of the base material.

Aluminothermic pressure welding is used in the plant as well as electro-resistance welding, but electro-resistance welding is much more common.

Fig. 3. Defect 421 (left) and 422 (right) [6]

Defects that can occur are: transverse cracking of the profile 421 (Fig. 3 - left) and horizontal cracking of the web 422 (Fig. 3 - right). They are observed visually or ultrasonically. The defect is eliminated by repair welding if possible.

4.2. Rails welded by flash-butt process

In this case, the ends of the rails are tightly clamped in a welding machine [4]. The electrodes for power supply are 12 - 16 cm apart. The ends of the rails to be welded do not need to be pre-processed, and can also be autogenously cut. They are brought close so that they touch easily, and then a current of 25000 A and a voltage of 5 V is supplied. When the current passes between the ends of the rails, a spark is created and heat develops (Joule effect). The machine successively moves the rails towards each other and away from each other, during which the steel particles burn and the rail ends are brought to the melting temperature. Now the rails are compacted under pressure, resulting in their shortening and the creation of metal filings at the seam. They are cleaned with a cutter and the seam is sanded, so that the rail profiles match perfectly. The execution time of one stitch is 2.5 – 3 minutes. The shortening of the rails is up to 15 mm.

Today, this is the fastest, cheapest and highest quality rail welding process. It is used in workshops because it requires massive, heavy equipment to perform the seams. Electricity consumption is high, although success has been achieved in this field in recent times.

With this welding method, rails with a length of at least 5 m – 6 m can be welded. The capacity of one rail is over 100 quality welds in one shift.

It is possible to perform the same welding procedure by welding in the track.

In Serbia, a PRSM-4 rail welding wagon was used.

Given that multiple rails with a factory length of mostly 30 m are connected in the CWR, by flash or aluminothermic welding, sometimes there are defects caused by welding, either from the formation of the CWR or from the repair of other defects. Defects that can occur are also: transverse cracking of the web 411 (Fig. 4 - left) and horizontal cracking of the web 412 (Fig. 4 - right). They are observed visually or ultrasonically. The defect is also eliminated by repair welding if possible.

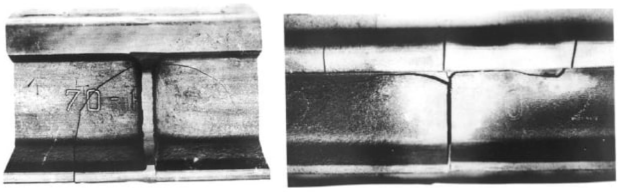


Fig. 4. Defect 411 (left) and 412 (right) [6]

4.3. Arc welded rails

The procedure consists in approaching electrodes that are under voltage and that create an electric arc on the composition of the rails [4]. The molten metal particles from the electrodes move to the rail and the dilatation opening between the two rails is closed. In this way, a layer of metal is applied to the metal, and in addition to welding the rails in the track, this procedure is also used for welding damaged places on the rails and turnouts, such as, for example, rails with skid marks of locomotive wheels or corroded turnout frogs and points.

The electrodes are 4 - 6 mm in diameter, 30 - 45 cm long. Air access to the electric arc can be harmful, so coated electrodes are used. The coating reduces the effect of air and improves the melt. Coated electrodes can be used for DC or AC welding currents. The current voltage is from 5 V to 40 V, and the current strength is from 20 A to 600 A. It is necessary to have a generator on the field if no connection to the existing network has been made.

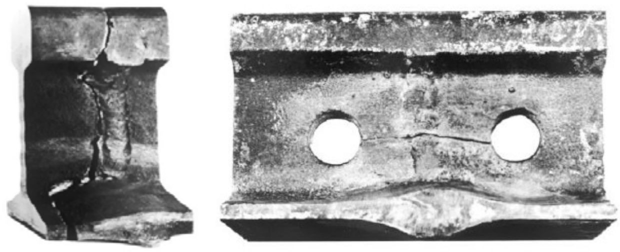


Fig. 5. Defect 431 (left) and 432 (right) [6]

The defects that can occur are the same: transverse cracking of the web 431 (Fig. 5 - left) and horizontal cracking of the web 432 (Fig. 5 - right). They are observed visually or ultrasonically. The defect is also eliminated by repair welding if possible. For the above case in Figure 5 - without hitting the rail foot with a hammer after the surfacing is complete.

4.4. Gas welded rails

This procedure does not require electricity, only a bottle of acetylene and a suitable apparatus. The composition of the rails can be well welded, but the quality depends a lot on the welder (usually two work together).

In the USA, gas compression welding is used. The ends of the rails are heated in the device with an acetylene flame, and then compressed as in the electro-resistant welding process.

5. DEFECT ANALYSIS

In order to analyze the data on all observed defects on the tracks Nis - Dimitrovgrad – Bulgarian border and Nis – Preševo – Macedonian border, a classification of defects was made based on rail parts.

Table 1 shows an overview of all rail defects on the two noted lines.

Tab. 1. Defects per section of rail - the last 56 months

Rail section/place	Defect quantity	Frequency distribution (%)
Rail end - fishplate	20	36,4
Flash-butt joint	4	7,3
Aluminothermic joint	16	29,1
Away from ends	17	30,9
Total	55	100

Many factors contribute to the formation of defects. Since all information included the time of year when the defects occurred, in order to find out how the frequency of defects varies with climate, additional attention was paid to determining the effect of climate on the occurrence of defects (Table 2 and Fig. 6) [10].

Tab. 2. The relationship between the season and the number of defects on the railway track rails - the last 56 months

Season	Defect quantity	Frequency distribution (%)
Spring	10	18,2
Summer	6	10,9
Fall	8	14,5
Winter	31	56,4
Total	55	100

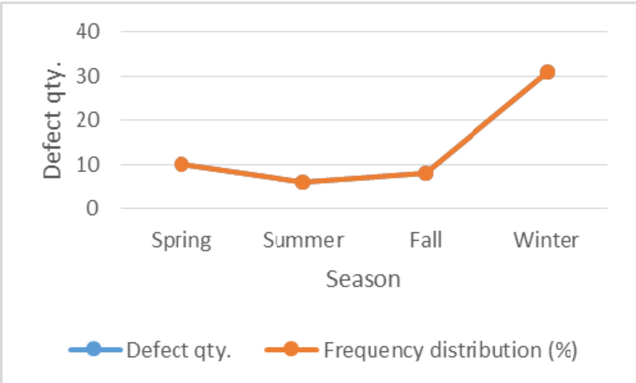


Fig. 6: The relationship between the season and the number of defects on the railway track rails - the last 56 months

The analysis revealed a relationship between seasons and failed components. It is clear that time plays a very significant role in the probability of failure. In Table 2, the seasonal defects represent a better representation of the influence of climate on failure, where a large number of failures occurred in the winter period. This means that cold weather is a problem of great importance to the railway system. Indeed, much attention should be paid to inspection during cold weather.

6. CONCLUSION

This analysis made it possible to identify the most common defects and the most critical parts of the rail along its length. Accordingly, in future works, failure risk assessment based on a wider range of data might support maintenance development by providing precise criteria for deciding how often routine tasks of the periodical maintenance should be performed. This policy could include improved inspection and repair service levels.

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IMPLEMENTATION OF THE FIRE ALARM SYSTEM INTO LOCOMOTIVES OF RAILWAY TRANSPORT AT THERMAL POWER PLANT NIKOLA TESLA

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Saša TRIVIĆ[2]

***Abstract** – In addition to causing great damage to nature and the environment, fire as an elemental disaster is one of the causes in technical and technological accidents, which results in large destructions and long-term failures of the process systems and in certain cases may also result in human casualties. In addition, in most situations, the aftermath of a fire is eliminated for an extended period of time, with the aim of restoring the condition before the accident. Railway traction vehicles (locomotives), whether electric or diesel traction, have in their composition electrical equipment which, by their function at work, convert different types of energy and into forms which, as a result, have thermal or light effects (sparks) which give conditions, leading to occurrence of fire. It should be noted here that the human factor, by its influence, poses a high risk of fire in locomotives. Prevention of these factors would be achieved by introduction of a modern fire alarm system, especially since the status monitor in the locomotive space is left to the automated system that catches fire at the earliest stage of occurrence and through the communication module notices arrive at predefined addresses, which alarms responsible people. A fire alarm system is a concept of a hardware-software device whose preferred elements are responsible for detecting conditions that can occur when a fire occurs.*

Keywords - technical and technological accidents, locomotives, electrical equipment, fire alarm system, detection and notification.

1. INTRODUCTION

Technical-technological accidents caused by fire are the most common reasons for accidents that occur in industrial processes as well as in all types of traffic, whether it is road, rail, air or water. Fire, as an elemental calamity whose effect leads to the devastation of nature and the environment, has the same effect on technical and technological systems. The main task of railway transport of PD TENT is the transportation of coal from the Mining Basin "Kolubara" for the needs of thermal power plants TENT-A and TENT-B[3]. The railway transport system for the delivery of coal to thermal power plants was built in 1969, and developed in parallel with the construction of the thermal power plants "Nikola Tesla" in Obrenovac (TENT-A) and Vorbis (TENT-B)[3]. The railway was electrified at the end of 1976, and now trains are hauled by electric locomotives of the 441 series, and in the event of a power outage and if there is a need for continuity of delivery, traction is carried out by diesel-electric locomotives of the 661 series[3]. For the purpose of loading coal, two loading stations have been installed near the mines of the "Kolubara" Mining Basin, for the needs of coal unloading at thermal power plants PD TENT has two unloading stations installed.

Loading and unloading of coal and necessary maneuvers in the stations are performed by shunting, electric locomotives of the 443 series[3].

After several incident situations due to the effect of fire during the previous years of operation of the locomotives and the analysis of the resulting damages as well as the fact that the mentioned means have been in use for more than thirty years and some for more than fifty, there was no doubt whether it was necessary to equip the locomotives 441, 443 and 661 series with fire detection and alarm system. The automatic fire detection and alarm system is intended to detect the occurrence of fire in its earliest stages, localize the place of fire occurrence, manage fire protection measures and report alarm conditions.

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2. FIRE AND CAUSES OF OCCURENCE ON LOCOMOTIVES

A fire is an uncontrolled spread of fire in space, causing material damage, and often taking human lives as well[1]. Fire is a rapid chemical process of binding fuel with oxidants with the release of heat and light energy[1]. During the process of burning under the influence of fire, temperatures ranging from a few hundred to more than a thousand degrees Celsius are developed, during which products are released in the form of smoke and gases that are very dangerous for the living world, and at the same time they contaminate the environment that is not covered by the fire. [1]. We often call this process the triangle of burning, but for the origin and development of a fire, a fourth condition is also needed, which is a continuous process of chain chemical reactions [1]. We can represent all four conditions as a burning tetrahedron. (Fig. 1.)

Fig.1 Burning tetrahedron

If one of these four conditions does not exist, there can be no ignition, and therefore no fire[1]. Burning itself is a controlled process, however, if it gets out of control, a fire occurs. Fire can be transmitted by conduction, radiation or convection[1]. Conduction is the transfer of heat through solid objects that takes place from molecule to molecule through the entire body of the object[1]. Heat is transmitted by radiation through invisible waves through space, and when it comes into contact with the body, it is absorbed, reflected or transmitted[1]. Convection is the transfer of heat through liquids and gases[1].

The causes of fires on locomotives can be different and can occur due to the effect of: thermal energy, electrical energy, chemical energy and mechanical energy. The most common are thermal, electrical and mechanical, although chemical causes of fire should not be neglected, even though they appear less frequently. Heat energy generators as a potential fire hazard are open flames (lighting cigarettes, using torches - in the winter months they are used to de-ice brake systems), incandescent bulbs, welding, grinding, etc. Electrical causes of fire are the most prevalent because locomotives are a set of electrical equipment and devices for which different voltage values are necessary for their operation, and therefore a greater amount of electrical energy is converted into thermal energy, which in itself represents the potential for fire. Overheating of electrical conductors, short circuits, and sparks due to switching changes in the state of the device are the most common causes of fire. The amount of heat energy is best illustrated by the data that at a current of only 20A, a temperature of 150°C and up to more than 300°C is released. A characteristic trace of a short circuit is a melted conductor or other parts of the installation and device, and as a result an electric arc whose temperature can be 1500 - 4000 °C. With the occurrence of these temperature levels, there are no non-combustible materials. Another interesting comparison is that the temperature on the surface of the sun is 5505 °C. Fig.2 shows the consequences after the fire that occurred on the locomotive 443 series in February 2019, in which the rectifier block that controls the traction motors was damaged. Due to this breakdown, the locomotive was out of service for 5 months, and the estimated damage was more than 11,000,000.00 dinars.

Fig.2 Totally destroyed rectifier bridge on locomotive 443 series

It is also important to mention the carriers of electrical energy that can lead to the development of fires, namely atmospheric discharges and static electricity. Mechanical energy carriers whose action can cause fire are various types of friction, which releases a large amount of thermal energy, often accompanied by sparks. The chemical causes of the release of energy potentially dangerous for fire on locomotives are oil used for cooling (traction transformer), accumulator batteries which are electrochemical generators as well as various types of lubricants, diesel fuel used by locomotives of the 661 series, etc.

3. FIRE PROTECTION

Fire protection includes a set of measures and procedures of a normative, administrative, organizational, technical and educational nature, determined by the Law on Fire Protection, by-laws, decisions of local government units, the selection and application of which achieves a higher degree of fire protection. The system of protection against fire and technological explosions includes norms of behavior of workers and third parties during work, movement and staying in plants and on construction facilities, as well as technical norms, norms and instructions related to construction, propulsion and other means of work[6]. Fire protection measures in railway vehicles are carried out through the maintenance of fire extinguishers. This is carried out through regular service inspections performed by the user of the vehicle, that is, by a legal or natural person designated by the user of the vehicle. In addition to fire extinguishers, the fire protection system on the locomotives in the TENT railway includes a fire detection and alarm system, but from the point of view of regulations, this area is not regulated in our country for now. The basis for the implementation of the mentioned system on locomotives in ŽT TENT from the point of view of regulation, were the norms applied for systems on stable facilities.

4. FROM IDEA TO REALIZATION

Different series of locomotives that are in use in ŽT TENT also perform different functions in the coal loading, delivery and unloading system. The importance of these functions was the starting basis for collecting the operating conditions of locomotives for the purpose of determining hazards and limit values, when determining which system to apply for fire detection and alarm.

Locomotives 441 series

Fig. 3 Locomotive 441 series

The 441 series locomotives are single-phase diode four-axle locomotives with single axle drive and engine power of 3,860 kW[2]. This type of locomotive uses four traction electric motors for its drive, and uses a 25 kV, 50Hz system for power supply. Locomotives have two control rooms, one at each end, in the middle is the engine room. The locomotive is about 15 m long and about 3 m wide (Fig. 3)[2].

Locomotives 443 series

Fig. 4 Locomotive 443 series

The locomotives of the 443 series are thyristor locomotives with a driving power of 880 kW[4]. It uses a 25 kV, 50Hz system for power supply. They are equipped with remote control and automatic low speed control. The locomotive has one control room in the middle, and two machine rooms in the front and back. The locomotive is about 14 m long and about 3 m wide (Fig. 4)[4].

Locomotives 661 series

Fig.5 Locomotive 661 series

The locomotives of the 661 series are diesel locomotives with a driving power of 1300 kW[5]. The locomotive has one control room, and the engine room is next to it. The locomotive is about 18.5 m long, about 3 m wide (Fig. 5)[5].

The review of technical documentation of locomotives, surveys in traction and maintenance services and data obtained from RHMZS collected relevant facts for finding a conceptual solution for the requested project. By inspecting the technical documentation, in addition to the basic characteristics of the locomotives, detailed data on the dimensions of the locomotive, the disposition of the equipment, the electrical installation of low and high voltage, the pneumatic installation, the function of the electrical circuits, the control system and other details that are interesting from the point of view of fire protection of certain devices on the locomotives were taken. Based on the obtained technical data, the protection zones in the locomotives and the power supply of the system were determined, which opened the way to a hardware solution. For example, the detector in traction zone 1 protects S1, S5 and S2 blocks (cabinets) that are in the function of traction motors (Fig. 6).

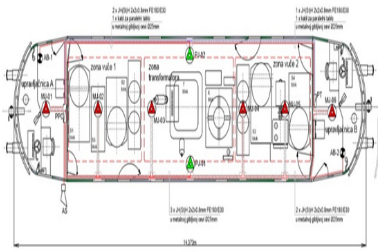

Fig. 6 Zone protection ext. 441 series

Important data for determining the characteristic of the detector that needs to be applied is the influence of weather conditions on the system in the area where the locomotives are used. Extreme weather conditions, low or high temperatures can have an impact on the function of the detector, which would lead to unreliability of the system, and therefore to increased risks of untimely notification of the occurrence of a fire. It is interesting that the data received from RHMZS show that in the area where the locomotives move, for the last 35 years, extremely low temperatures below -20°C and extremely high temperatures over +40°C have occurred several times. Most detectors that are used in closed stable facilities are for operating conditions from -10°C to +40°C Celsius.

By surveying the personnel engaged in the maintenance of locomotives, data was obtained on the method of equipment maintenance, disassembly and working conditions in the engine rooms of locomotives, as well as on the condition and function of devices and assembliesThe information obtained by surveying the personnel operating the locomotives (engine drivers) was used to determine the function of the detectors in the cabs, the position for the fire detection and alarm control panel. The analysis of the collected data provided the basis for finding a technical solution that will be used for the development of design documentation, without which there is no implementation of the required system on locomotives.

5. TECHNICAL SOLUTION

Locomotive 441 and 443

A compact, addressable, microprocessor-controlled fire alarm system was used for these locomotives (Fig. 7) [3]. Each detector has its own address, and on the control panel, through the text display, it enables a quick and unambiguous definition of the place of occurrence of the fire[3].

Information on the state of the system, as well as the alarm state, are displayed and signalled on the control panel, with sound and text on the LCD[3]. All lines of the system are permanently monitored in the event of a line break, ground fault or short circuit [3]. The central unit for automatic detection and fire alarm is powered from a separate 220V alternating voltage outlet, which is formed on the inverter 72V DC/ 220V AC[3]. A self-powered power supply system was also implemented in case of mains power failure, which was realized by installing batteries with 72-hour autonomy[3].

Fig. 7 Control center/ panel for the fire detection and alarm system

Locomotives 661 series

Detection and reporting of fires in the series of these locomotives is carried out via a conventional switchboard with 4 conventional reporting lines[3]. Power supply to the control center is achieved through a 72Vdc/220Vac[3] converter.

Alarm and error signals are generated via programmable outputs, which are forwarded to the authorities via SMS messages via the GSM pager[3]. The GSM pager is powered from the control panel. Since the building does not have an automatic fire extinguishing system, it is necessary to involve a person in the alarming procedure in order to take advantage of the early fire detection system and start extinguishing the fire in its initial stages, when the fire can be extinguished with hand extinguishing means[3]. The person on duty is obliged to be familiar with the system and to react quickly according to the nature of the message he receives from the notification system[3]. The working algorithm of the fire alarm control center is given in Fig. 8 [3]:

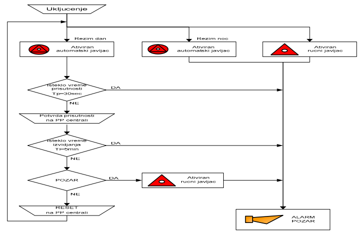

Fig. 8 Algorithm of the alarm plan

6. CONCLUSION

The purpose of the innovative solution in the form of the implementation of a fire alarm system on locomotives owned by ŽT in TENT is to increase the reliability of the operation of locomotives in the coal delivery process by reducing the risk of fire. Timely reaction upon reaching the conditions for the occurrence of fire is one of the crucial elements for the prevention of technical - technological accidents of a wider scale, which protects material resources and human lives. Railway transport, as well as the thermal power plants that it serves, are in a continuous process of operation of 24 hours a day, 365 days a year for the last 40 and more years with a tendency and a view into the distant future. In order to achieve the aforementioned requirements, modernization and implementation of technical-technological solutions and innovations must be carried out with rapid steps, by introducing modern control systems and automatic regulation in energy and process technology. Together with the TENT Branch, ŽT keeps up with the constant modernization of its process through investments and in return receives reliability that is at the level of a new system. For the sake of comparison, the damage mentioned in this paper with the stated financial item exceeds the investments allocated for the installation of a fire alarm system on 20 locomotives.

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VIBRATION TESTING DMV 711 SYSTEM BASED ON XLP TECHNOLOGY

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Abstract *– The 711 series diesel train is exposed to serious dynamic influences during operation, which originate from the contact of the wheel rails and the drive group. Dynamic influences originating from the contact of the wheel rails and which are dominant in their intensity cause vibrations, which are transmitted through the primary suspension to the frame of the bogie and from there through the secondary suspension to the rest of the diesel train. It should be noted that there are two types of bogies (drive and free) on the 711 series diesel motor train. In addition to the dynamic influences from the contact of the wheel wheels, the drive swivel in relation to the free swivel stand is additionally loaded by the dynamic influence from the drive group. Vibrations that occur as a result of dynamic influences can cause great damage to the construction of a diesel motor train. The main goal of this paper is to determine the intensity of vibrations that are transmitted to the frame of the drive bogie via the contact of the wheel and rails. For that purpose, DMV 711 was tested on the section of the railway between Nis and Svrljig. The test was performed with a vibration diagnostic system based on XLP technology.*

Keywords – Diesel motor train, dynamic impact, bogie, vibration diagnostics system.

1. INTRODUCTION

Dynamic influences originating from the wheel-rail contact and which are dominant in their intensity cause vibrations, which are transmitted to the frame of the bogie through the primary suspension and from it through the secondary suspension to the rest of the diesel engine train. Vibrations that occur as a result of dynamic influences can cause major damage to the structure of a diesel engine train.

The main goal of the work is to determine the intensity of vibrations that are transmitted to the frame of the driving bogie through the wheel-rail contact. For this purpose, DMV 711 was tested on the railway section between Nis and Svrnjig. The test was performed with a vibrodiagnostic system based on XLP technology.

2. VIBRODIAGNOSIS SYSTEM

For the purpose of testing DMV 711, a vibrodiagnostic system was used based on Microchip's microcontroller PIC16F877A (20MHz) for RS232 connection with a PC or on the basis of PIC18F4550 if connection via a USB port is required. The additional board is a 12-bit A/D converter with 4 channels based on the MCP3204 AD converter. The device has:

- 8 analog input channels (range 0-5 V and 0-200 mV, other ranges are possible, all are protected up to 250 V);
- digital temperature sensor (-55 to 125) ˚C resolution 0.1 ˚C;
- liquid conductivity sensor;
- Hall sensor of high sensitivity (-5 mT up to +5 mT)
- accelerometer and tilt sensor on 2 axes (x,y)

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range ±2 g.

2.1. ADXL311 acceleration sensor description

The ADXL311 is a two-axis acceleration sensor that performs signal filtering with low power consumption. The basic characteristics of this acceleration sensor are high operational reliability, at level 1 FIT, i.e. one failure per billion samples. Advantages, ADXL311 are small dimensions 5x5x2 mm.

The ADXL311 measures accelerations in the full range of ±2 g (g=9.81 m/s^2), and their operating voltage is in the range of 2.5 - 5.25 V, with a sensitivity of 200 mV/g, in addition, it simultaneously measures and static (gravitational force) and dynamic acceleration. The output signal is an analog voltage proportional to the acceleration. The sensor can be used in a wide range from 1 Hz to 1 kHz, depending on which set of capacitors is connected to the operation (tab. 1).

Tab. 1. Measuring range depending on the capacitor used

Bandwidth	Capacitor (μF)
10Hz	0.47
50Hz	0.10
100Hz	0.05
200Hz	0.027
500Hz	0.01
5kHz	0.001

The operating temperature of the sensor ranges from -55 to +125 degrees Celsius (Figure 1). In the basic configuration, the accelerometer has a range of up to 1 kHz, using a 0.001 µF capacitor and a 50 kΩ resistor, which reduces noise, and reduces the accelerometer supply current by 25 µA.

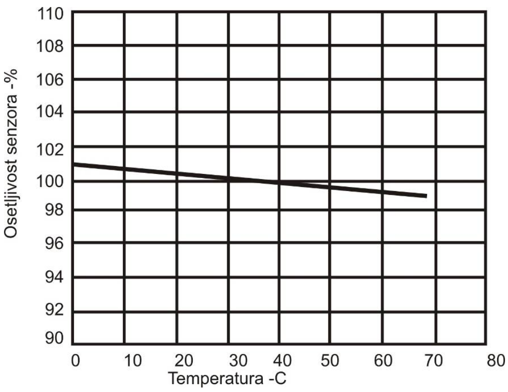

Fig.1. Diagram of the effect of temperature on the sensitivity of the sensor

The noise that occurs during measurement depends on the measuring range of the sensor. As the measurement range increases, the noise increases, according to the formula $\mu g / \sqrt{Hz}$, that is, the noise is proportional to the square root of the sensor bandwidth.

The PIC16F877A microcontroller has five ports (PORT_A, PORT_B, PORT_C, PORT_D and PORT_E) and all of them represent the connection of its internal structure to the external environment. Each of them can be configured as input or output. The mentioned five ports are of different scope:

- 6-pin (PORT_A),
- 8-pin (PORT_B, PORT_C, PORT_D),
- 3-pin (PORT_E).

Each pin of any port, depending on the operating mode, can be assigned both fixed and variable functions. The configuration of the transmission direction is achieved by writing to the appropriate bit position in the associated TRIS register (0 – pin is output, 1 – pin is input).

Each port is assigned a data register (PORT_X), through which the I/O pins are programmatically accessed. An entry in one of those registers will initiate an entry in the latch of that port (latch-accepting registers for saving the state of the outputs on the ports), and its reading will result in determining the logic states directly from the pins. All writing instructions are of the read-modify-write type. This means that when writing to the port, the states of the pins are first read, then the modification is made, and then the corrected value is written into the port's latch. There is no big difference in the construction of the mentioned five ports. Only Port_B differs from the others due to the special option provided by the four MSBs.

The PIC16F877 microcontroller has several useful peripheral modules. A microcontroller usually does not work alone, but is part of a network of devices that communicate with each other and exchange data. For this purpose, the microcontroller is equipped with three hardware communication modules.

The first of them is the SSP module (Synchronous Serial Port), which serves for communication with serial EEPROMs, floating registers, display drivers, etc. This module can work in one of two modes:

- SerialPeripheralInterface (SPI),
- Inter-Integrated Circuit (I2C).

Another serial communication module is the USART (Universal Synchronous Asynchronous Receiver Transmitter). It is mainly used for connecting to a personal computer, although this is not the only possibility of its application.

The USART can be configured in one of the following operating modes:

- Asynchronous operation (fullduplex),
- Synchronous master work (half duplex),
- Synchronous slave operation (half duplex).

Apart from serial, there is also a parallel communication module. It is about the PSP (Parallel

Slave Port) module. Its task is to connect the PIC16F877A directly to the 8-bit data bus of another microprocessor. The external microprocessor can then, via the Read (RD) and Write (WR) lines, read and write to the Port_D register like any other 8-bit latch.

Most analog filters are required to extract the desired signal from the complex signal. Almost complete extraction of the desired signal is only possible if the signal spectra are separated. But even then, the degree of separation and the quality of transmission of the desired signal is still limited, mainly by the quality of available components and noise in the environment.

The frequency range of the desired signal is called the bandwidth. In an ideal case, in order for the desired signal to be transmitted without distortion and with as little attenuation as possible, it is necessary that the amplitude characteristic and the group delay characteristic be constant in the bandwidth. These requirements cannot be met with real networks containing a finite number of lumped parameters. Therefore, the upper and lower limits between which the variation of the amplitude characteristic is acceptable are specified (prescribed, that is, set). The choice of these limits is influenced by the tolerances of the components, as well as their dissipation. The limits at the edges of the bandwidth are wider due to the increase in dissipation.

In theory, filters can have multiple split bandwidths. In practice, those with one bandwidth, that is, one non-passable bandwidth, are mostly used. These are: low-pass filter (LOWPASS FILTER - LP), high-pass filter (HIGHPASS FILTER - HP), bandpass filter (BANDPASS FILTER - BP) and bandpass filter (BANDSTOP FILTER - BP, BANDREJECT FILTER BR).

3. VIBRATION TESTING ON THE DMV 711 TRAIN

The DMV is intended for passenger transport on normal-gauge railways, equipped with low platforms (Figure 2). It consists of two circuits. The maximum design speed of the DMV is 120 km/h. It is powered by an MTU 6H 1800 R83 four-stroke six-cylinder diesel engine with direct fuel injection and a turbocharger.

The reliable operation of all assemblies and devices is designed for operation in the following climatic conditions:

- ambient temperature from minus 25 to plus 40 ºC, with reduced technical characteristics at temperatures from minus 25 to minus 30 ºC;
- relative air humidity 90%;
- altitude for reliable operation maximum 600 m.

Fig.2. DMV 711

The test of the load suffered by the structure of the diesel engine train was carried out on the route Niš - Svrljig on February 11, 2022. year on train number 2742. The mentioned route was chosen for the reason of noticing the difference in the loads that the structure of the DMV suffers on the unrepaired and repaired part of the railway. Namely, the railway line from Niš to Matejevac has not been repaired, while it has been repaired from Matejevac to Svrljig.

In order to measure the direct effects of the load between the wheel and the rail, which the diesel engine train suffers, an acceleration sensor is placed on the bearing housing of the drive axle (Figure 3).

Fig.3. Acceleration sensor installed

During the test, performance measurements were taken on certain parts of the section in time intervals of 2.238 s. Data on measurements are recorded in text files, which contain data on accelerations in the x and y directions. On the section between Niš and Matejevac, the maximum train speed was 40 km/h. By processing the obtained data, the results of measurements on this section are shown graphically

(Figure 4).

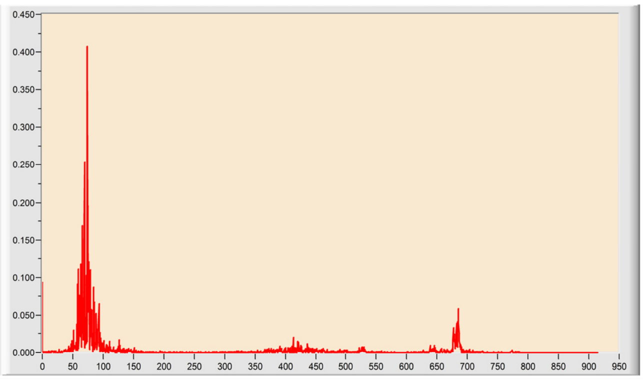

Fig.4. Niš - Matejevac route

The diagram shows frequency data and mean acceleration that loads the structure. By analyzing the measurement results, we can conclude that DMVs on this section are burdened by high impact loads at low frequencies (between 50 and 100 Hz).

On the section between Matejevac and Svrljig, the maximum train speed was 70 km/h. By processing the obtained data, the results of measurements on this section are shown graphically (Figure 5).

By analyzing the measurement results, we can conclude that DMVs on this section are burdened by small impact loads that occur in the spectrum from 0 to 550 Hz.

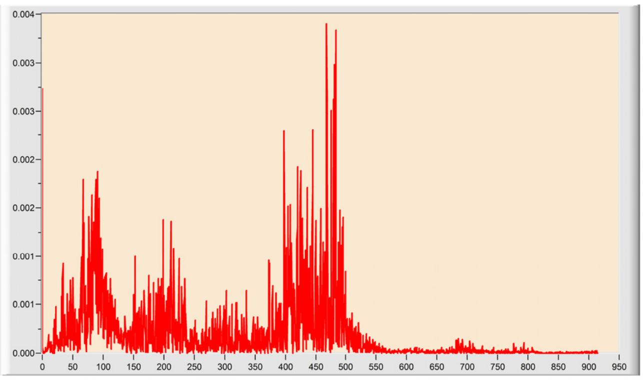

Fig.5. Matejevac - Svrljig route

4. CONCLUSION

The vibrodiagnostic system, which is presented in the paper, has the possibility of great application when testing vibrations on railway vehicles.

The vibrodiagnostic system requires almost no preliminary work before application. It is very easy and quick to assemble and disassemble from the railway vehicle, which is being tested. In this way, it is possible to perform a number of different measurements without disturbing the regular operation of the railway. As an example of the advantages of using the vibrodiagnostic system, the testing of DMV 711 on the Niš - Svrljig railway was carried out. Assembly and disassembly of the vibrodiagnostic system took about one minute, which did not jeopardize the schedule of the DMV 711.

The test results showed that DMV 711 on the unrepaired part of the track, regardless of the fact that it was moving at a maximum speed of 40 km/h, suffers heavy loads at low frequencies, which in the extreme case can lead to damage to certain vital components of the railway vehicle. The conducted test also showed that on the repaired part of the railway, the DMV, which was moving at a maximum speed of 70 km/h, suffers very little loads.

From all that has been stated, it can be concluded that the presented vibrodiagnostic system is very useful for collecting the necessary data from exploitation, all in order to determine all the weak points in the construction of the DMV.

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XX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
RAILCON '22

BALANCING EMV 413/417 ON RAILWAYS IN THE REPUBLIC OF SERBIA

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Abstract *– Balancing the train is very important for the reason of stability of movement, ride quality and even loading of all wheels. In this way, equal wear of the wheel rims is achieved and thus contributes to lower train maintenance costs. Balancing the train just balances the train.The aim of this paper is to balance the electric train (EMV 413/417) based on the manufacturer's documentation. The calculation and analysis of the obtained results proved that EMV 413/417 does not meet the criteria prescribed by the Rulebook for maintenance of railway vehicles for traffic on railways in the Republic of Serbia. The calculation of the work will calculate the required ballast masses by axles and wheels EMV 413/417. At the same time, an amendment to the existing Rulebook for the maintenance of railway vehicles will be proposed.*

Keywords – Stability of movement, train balancing, train weighing, ballast mass, Rulebook.

1. INTRODUCTION

Each railway vehicle is a separate technical system consisting of a large number of subsystems, assemblies, subassemblies and elements. The operation and functionality of each of them is directly related to the overall working ability of the system in operation. One of the most important performance characteristics of a railway vehicle is its balance. This is important both from the side of comfort when moving the vehicle (smooth gait) and from the side of less possibility of wheel wear. By balancing the railway vehicle, the service life of the wheels is extended.

The subject of research in this paper is the balancing of electric train 413/417. After a comprehensive analysis and processing of the available data as a result of calculations, certain conclusions were reached regarding the use of the electric train 413/417 on the railways in Serbia.

2. WEIGHING OF ELECTRIC MOTOR TRAIN 413/417

One of the tasks of the control of railway vehicles is the weighing of railway vehicles. Weighing determines the total mass of the railway vehicle and the distribution of mass on individual axles, i.e. wheels, as well as the average mass based on all axles in the vehicle, i.e. all axles in the bogie, mass per wheel, vehicle mass per wheels on the left and right sides of the vehicle. Weighing can be preceded by suspension adjustment, which checks the dimensions.

Weighing of railway vehicles is carried out after:

- completed construction of a new vehicle;
- regular vehicle repairs;
- extraordinary repairs, renovations and upgrades of the vehicle, if these works could affect the change in the total weight of the vehicle or the distribution of the weight on the vehicle;
- after periodic inspections where the scope of the works provides for it.

Before acceptance tests during weighing, as well as when checking dimensions, a test of the loaded vehicle is carried out. The following types of vehicle load are distinguished:

- the smallest load that will allow the vehicle to move under its own power or to be towed;
- normal load used for performance testing e.g. in engine mode or in braking mode and

overload, which represents the maximum load that the vehicle can safely handle.

The mass defined by the manufacturer's project for a vehicle ready for service with 2/3 of the supply of consumables and equipment that is an integral part of it is the nominal total mass of the vehicle.

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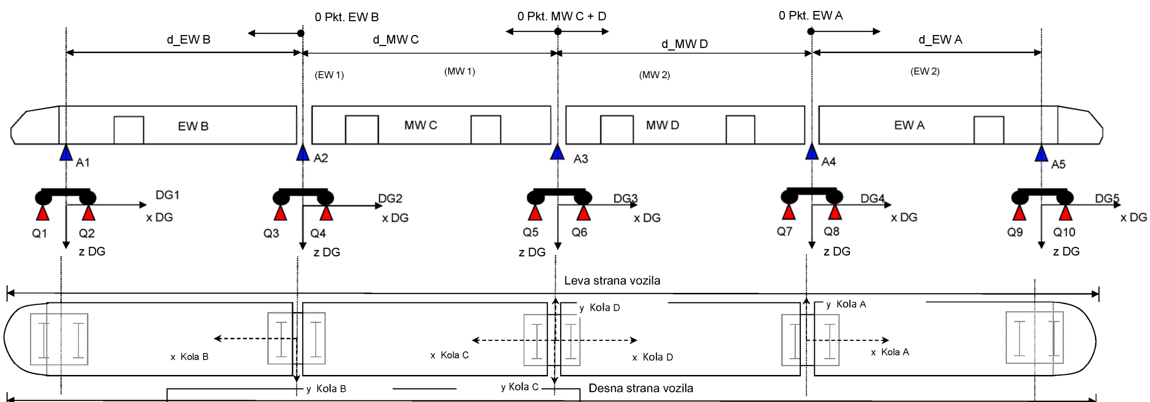

	Kola B		Kola C	Kola D	Kola A
Rastojanje između svornjaka	15800		17500	17500	15800
Širina	2820		2820	2820	2820
Razmak kruga kotrljanja	1500		Polurastojanje kruga kotrljanja:	750	

Tara	Nema standarda	Sopstvena masa bez pogonskog materijala (zalihe), sa pogonskim sredstvima	Prazna težina vozila bez zaliha i bez osoblja
Tara 2	Nema standarda	Tara sa kompletnim pogonskim sredstvima, pogonskim materijalima i zalihama	100% zalihe za vozila spremna za vožnju (pesak + voda); bez osoblja
Bruto 1	DIN 25008; izd. okt. 05	Maksimalna masa, regionalni i prigradski saobraćaj	Osoblje + 100% zalihe + mesta za sedenje bez preklopnih sedišta po 75 kg, 500 kg/m2 površina za mesta za stajanje
Bruto 2	Funkcionalni spisak Srbija	Maksimalno statičko osovinsko opterećenje	Mesta za sedenje bez preklopnih sedišta po 80 kg + mesta za stajanje 4 osobe/m2; 2/3 pogonskog materijala

Fig.1. Schematic view of EMV 413/417 load

The mass of the vehicle ready for service is the mass determined by measuring the vehicle ready for service with 2/3 stock and the equipment that forms an integral part of the vehicle is the actual total mass of the vehicle. It is obtained as a result of the measurement of the entire vehicle, as a sum of the results of measuring the mass per axle of all axles in the vehicle (sum of the masses on the left and right wheels for each axle of all axles in the vehicle), that is, as a sum of the results of measuring the mass per wheel of all the wheels of the vehicle.

If the construction of the vehicle provides for the same value of mass per axle of all axles in the vehicle, the average mass per axle is obtained by dividing the total mass of the vehicle by the number of axles. If the vehicle construction does not provide for the same mass value per axle for all axles in the vehicle, the average mass per axle is calculated for each group of axles where the vehicle construction provides the same mass value per axle, whereby only that part of the actual mass that is taken as the actual mass of the vehicle is taken falls on the respective group of axes.

The goal of weighing is to check whether the maximum or minimum load corresponds to the values specified in the project. Before weighing, suspension adjustment can be performed, which, in principle, does not require load measurement, but only dimensional checks. Vehicle weighing involves four consecutive measurements (to reduce errors arising from balancing and friction), whereby vehicles must move in both directions twice. After the first measurement, the results are checked and if a significant deviation from the permitted values is found, the adjustment of the distribution of masses by axles is started, after which the measurement is performed again. The procedure is repeated until the permissible deviation of the distribution of masses per axle is reached. After each individual measurement, the vehicle is pulled off the scale. All weights are entered and the arithmetic mean of all measurements is determined.

The results of vehicle weighing are recorded in the measurement list. The completed measurement list is certified by the representative of the workshop and the representative of the person in charge of maintenance.

Weighing of motor trains after regular repair, extraordinary repair, renewal or improvement, which has no significant influence on the distribution of masses, is performed only without load (without passengers, i.e. suitable load as a replacement for passengers). In the case of motor trains after completion of construction or after renovation or upgrading, during which there was a change in the distribution of masses, which may have a significant impact on the distribution of masses by axles, the following weighings are performed:

- with a load that simulates the layout and mass of passengers;
- without load, which simulates the layout and mass of passengers (weighing of other motor trains from that series is performed only without load).

Procena		[kg]	Krajnja kola B		Srednja kola C	Srednja kola D	Krajnja kola A		Zbirovi
Pojedinačna težina			26734		16151	13743	26749		83377
Šasije			Pogonsko obrtno postolje 1	Slobodno obrtno postolje 1	Slobodno obrtno postolje 2	Slobodno obrtno postolje 3	Pogonsko obrtno postolje 2		
			12573	6570	6120	6570	12573		44406
Tara (sopstvena masa bez radnih zaliha)									127783
Tara 2	Dopunsko opterećenje		120		200	0	120		440
	Pojedinačna težina + dopunsko opterećenje		26854		16351	13743	26869		83817
	Tara + dopunsko opterećenje								128223
Bruto 1	Dopunsko opterećenje		9905		14033	11865	10518		46321
	Pojedinačna težina + dopunsko opterećenje		36639		30183	25608	37267		129697
	Tara + dopunsko opterećenje								174103
Bruto 2	Dopunsko opterećenje		8036		10407	9770	8527		36739
	Pojedinačna težina + dopunsko opterećenje		34770		26558	23513	35276		120116
	Tara + dopunsko opterećenje								164522
Procena		[kg]	Krajnja kola B		Srednja kola C	Srednja kola D	Krajnja kola A		Zbirovi

Sile oslanjanja raspodeljene prema delovima pojedinačnih kolskih sanduka

	[kg]	Kola B		Kola C		Kola D		Kola A	
Sile oslanjanja	[kg]	A1	A2-1	A2-2	A3-1	A3-2	A4-1	A4-2	A5	
Tara (sopstvena težina)		19660	7074	7762	8389	7223	6520	7070	19679	83377
Sila oslanjanja dopunskog opterećenja		120	0	124	76	0	0	0	120	440
Tara 2 (uklj. zalihe)		19780	7074	7886	8465	7223	6520	7070	19799	83817
Sila oslanjanja dopunskog opterećenja		4750	5155	6871	7161	5574	6291	5278	5240	46321
Bruto 1 (tara + dopunsko opterećenje)		24410	12229	14633	15550	12797	12811	12348	24919	129697
Sila oslanjanja dopunskog opterećenja		3786	4250	4899	5508	4632	5138	4351	4176	36739
Bruto 2 (tara + dopunsko opterećenje)		23446	11324	12661	13897	11855	11658	11421	23855	120116
Sile oslanjanja		A1	A2-1	A2-2	A3-1	A3-2	A4-1	A4-2	A5	
		Kola B		Kola C		Kola D		Kola A		

		[kg]	Kola B		Kola C			Kola D		Kola A	
			A1		A2		A3		A4		A5
Statička osovinska opterećenja		[kg]	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	
Tara (sila oslanjanja + šasija)	Opterećenje po točku, levo		8154	8004	5347	5352	5428	5434	5035	5040	7968	8116	63879
	Opterećenje po točku, desn		8111	7963	5351	5356	5432	5439	5040	5045	8009	8159	63904
	Statičko osovinsko optereć		16266	15968	10698	10708	10859	10873	10075	10085	15977	16275	127783
Tara 2 (sila oslanjanja + šasija)	Opterećenje po točku, levo		8184	8034	5378	5383	5447	5454	5035	5040	7998	8146	64099
	Opterećenje po točku, desn		8141	7993	5382	5387	5451	5458	5040	5045	8039	8189	64124
	Statičko osovinsko optereć		16326	16028	10760	10770	10898	10911	10075	10085	16037	16335	128223
Bruto 1 (sila oslanjanja + šasija)	Opterećenje po točku, levo		9342	9192	8353	8358	8611	8618	7928	7932	9278	9426	87039
	Opterećenje po točku, desn		9299	9151	8358	8363	8615	8622	7932	7937	9319	9469	87065
	Statičko osovinsko optereć		18641	18343	16711	16721	17227	17240	15860	15869	18597	18895	174103
Bruto 2 (sila oslanjanja + šasija)	Opterećenje po točku, levo		9101	8951	7634	7639	7962	7969	7408	7412	9012	9160	82248
	Opterećenje po točku, desn		9058	8910	7638	7643	7966	7973	7412	7417	9053	9203	82274
	Statičko osovinsko optereć		18158	17860	15273	15282	15929	15942	14820	14829	18065	18363	164522
Statička osovinska opterećenja		[kg]	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	
			A1		A2		A3		A4		A5		
			Kola B		Kola C			Kola D		Kola A			

Fig.2. Tabular presentation of EMV 413/417 load

Permissible deviation when weighing motor trains:

- total mass of the motor train: +5% and -1% of the nominal total mass;
- weight per axle: ±2% of the average weight per axle;
- sum of masses per wheels of one row of wheels: ±4% of the mean value;
- mass per wheel of one axle: ±4% of the mean value.

Figure 1 shows a schematic representation of the axle load of an electric train, and Figure 2 shows the calculation of the axle load of Flirt ŽS of the Serbian Railways.

The FLIRT 3 train, i.e. EMV 413/417, built for the needs of "Serbian Railways" is four-part (with configuration B-C-D-A) and has five bogies (two driven and three free), so that all connections between them they rely on a common foundation.

The total weight of the empty train is about 127 tons. The static axle load of EMV - gross 2 is 164,522 kg, of which 82,248 kg is on the left wheel, and 82,274 kg is on the right wheel.

2.1. EMV balancing check

Based on the calculations given by the manufacturer, the axle masses of the electric train are shown graphically in Figure 3.

When the percentage differences in the masses of each axle are calculated in relation to the average value of the masses of the axles, the values are obtained which are graphically shown in Figure 3.

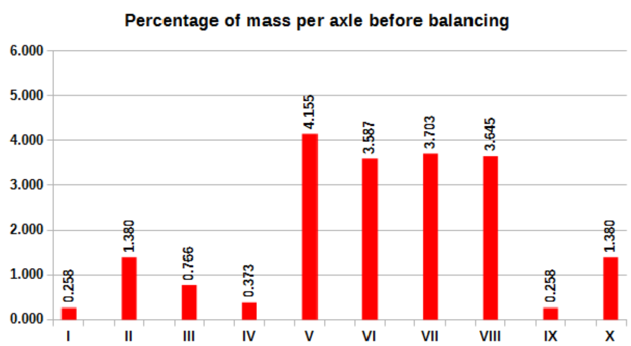

Fig.3. Percentage deviation of the mass of axles in relation to the average value

Based on the values shown on the graph (fig. 3), the V, VI, VII and VIII axles on EMV 413/417 do not meet the specified conditions for weighing the train, i.e. the condition that the mass of each individual axle must move within the limits of ±2% is not met. Therefore, EMV 413/417 **it does not meet the criteria of moving on the railways in the Republic of Serbia.**

3. BALANCING EMV

In order to meet the conditions required for balancing the train, it is necessary to balance the masses of the axles. Balancing the train can be done in two ways:

- redistribution of masses and
- by installing the necessary ballasts on the electric train.

The values of the required ballast per axle are shown in Figure 4.

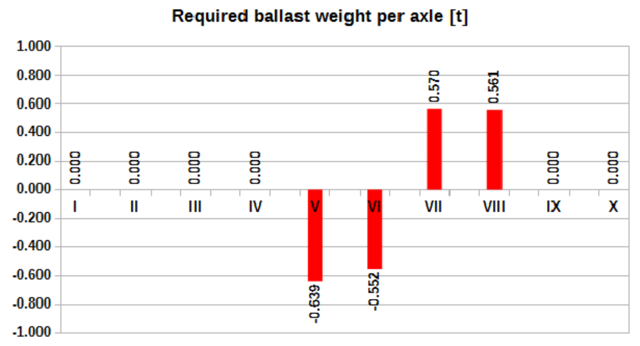

Fig.4. Ballast masses required per axle to balance the EMV 413/417

After the calculation of the required ballast masses, the percentage differences of the axle masses in relation to the average value are re-checked. Figure 5 shows a graphic representation of the percentage differences in the mass of the axles in relation to the average value, which after balancing is 18,192t for the drive axles and 15,380t for the free axles.

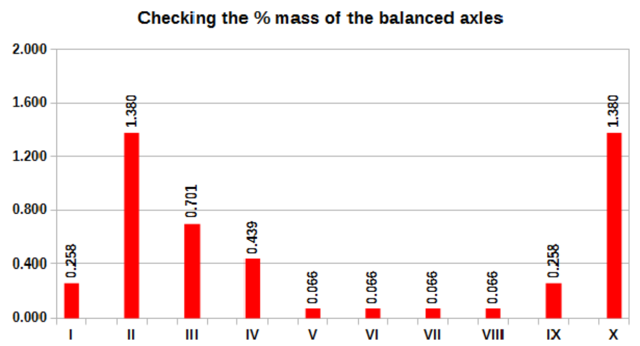

Fig.5. Percentage difference of balanced axles

Based on the results of the check, it is concluded that EMV 413/417 after balancing meets the set criteria for train balancing.

4. CONCLUSION

The calculation and analysis of the obtained results proved that EMV 413/417 does not meet the criteria prescribed by the Rulebook for the maintenance of railway vehicles for traffic on railways in the Republic of Serbia. Bearing this in mind, the ballast calculation was performed (Fig. 4), as one of the ways to balance EMV 413/417. From the graph (Fig.4) it is clearly seen that axles V and VI should be unloaded, while axles VII and VIII should be loaded.

It is also necessary for EMV 413/417 to prepare a necessary measurement list that would contain the following elements:

- masses of driving bogies;
- masses of free bogies;
- masses of drive axles;
- masses of free axles;
- masses of the wheels of the drive axles;
- masses of the wheels of the free axles.

At the same time, it is necessary to supplement the Rulebook on the maintenance of railway vehicles. The amendment would be in Annex 1 of the Rulebook in point 17 in the section on permitted deviations in the weighing of motor trains. Therefore, the amended point 17 in the section on permitted deviation in weighing motor trains would read:

Weighing of motor trains after regular repair, extraordinary repair, renewal or improvement, which has no significant influence on the mass distribution, is performed only without load (without passengers, i.e. suitable load as a substitute for passengers) **by previous application of point 6 of this attachment.** Further text in Annex 1 of the rulebook remains unchanged.

Applying the amendment to the regulations, weighing EMV 413/417 would imply the following criteria:

- total mass of the motor train: +5% and -1% of the nominal total mass;
- mass per drive shaft: ±2% of the average mass per drive axle;
- mass per free axle: ±2% of the mean mass per free axle;
- mass per wheel of one drive axle: ±4% of the mean value of measured mass per wheel of one drive axle;
- mass per wheel of one free axle: ±4% of the mean value of measured mass per wheel of one free axle;
- the sum of the masses per wheel of one row of driving wheels: ±4% of the mean value of the measured masses per wheel of one row of driving wheels.
- the sum of the masses per wheel of one row of free wheels: ±4% of the mean value of the measured masses per wheel of one row of free wheels. At the same time, an electronic form for checking the balance of EMV 413/417 was created, in the Calc program, which is an integral part of the LibreOffice software package.

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Strategy and Policy

XX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
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FUTURE TRENDS AS REQUIREMENTS IN THE EDUCATION OF RAILWAY ENGINEERS

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Abstract *– The accelerated implementation of new technologies in the liberalized and globalized (railway) market imposes many challenges in the process of educating railway engineers. In such circumstances, he is required to quickly respond to a broad spectrum of demands posed before him, through the improvement of his skills and competences. In order to be able to sound the requirements for the skills and competence of a modern railway engineer, it is necessary to clearly define which megatrends have a key influence on the future process of railway engineer education. This paper studies the key trends of the new age which need to be taken into consideration in the development of railways, and which should be taken into account when determining the knowledge and skill structure for a railway engineer.*

Keywords – railway engineer, megatrends, competencies, skills.

1. INTRODUCTION

The European railway sector has been in constant change since 1991. The Single European Railway Area required market liberalization and restructuring of incumbent railway companies from the period of monopoly. At the same time, there is an accelerated implementation of innovations and new technologies on the railways. The two mentioned factors have a strong influence on the change in requirements for the education of railway engineers, as well as for additional training, i.e. the acquisition of new skills.

In addition to the changes mentioned, the railway sector, experiencing with major changes, are affecting workforce: on one hand, about 30% is expected to retire in the next decade; on the other hand, the major transformation process driven by research and innovation, with special reference to digitalisation and automation, requires bringing in suitable skills and competencies. Digitalisation is progressing rapidly and is leading to an increased demand for more ICT and broad technical skills, as well as for soft skills. Moreover, there is a growing need for skills related to modernisation of rail infrastructure, traffic management and rolling stock.

In such circumstances, a major challenge to be faced is to clearly define megatrends and their influence on working condition, identification and anticipation of competence and skills needed, as well as difficulty to recruit people, including underrepresented groups such as women and young people. This is due especially to two aspects: a widespread, negative perception of working conditions in rail, and a low awareness about the high-tech job opportunities that are offered by the sector, with the introduction of novel railway technologies.

Which are megatrends that influence the rail skill ecosystem, to a new strategic approach to rail staff and student's education as well as sectoral cooperation for manufacturing of rail products and services; rail operation, maintenance and infrastructure management; ICT skills related to the use of digital technologies in the manufacturing of rail products and digitalisation in rail transport (such as Internet of Things, data analytics, and cybersecurity) need to be explore deeply.

This paper deals with the megatrends identification and classification that need to be taken into account when determining the necessary knowledge and skills of future railway engineers within the Single European Railway Area (SERA).

2. CHANGES IN THE ENVIRONMENT AFFECTING THE STRUCTURE OF NECESSARY KNOWLEDGE AND SKILLS

All key trends (megatrends) which need to be taken into account while determining the structure of knowledge and skills of a railway engineer can be divided into 4 basic groups [1], [2], [3], [4]:

1) Society,

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2) Technical and Technological,
3) Environment and politics,
4) Economics and market.

Each of these 4 megatrends contains numerous trends (subtrends) which need to be separated and evaluated while performing the innovation of an educational program. In this paper we did not perform neither evaluation nor prioritarisation of these trends, rather we have only distinguished key trends which, in our estimation, need to be taken into account.

We have also given short annotations to explain why these trends are the ones we have taken into account.

2.1. Social changes

Until now, factors of social changes and their accompanying trends have not been considered while creating a railway engineer’s educational framework. However, the influence of these factors (demographic, behavioural, cultural and socio-economic factors) is going to be exceptionaly significant in the coming years (decades).

A lack of qualified workforce will be especially obvious across Europe, and it is already observable for some particular professions such as train engineers and technical engineers. The following occurences are pointing to this [3], [4], [5]:

- many experts will retire in the coming years,
- qualification requirements are changing,
- the railway sector is generally perceived as unattractive,
- the share of women in total employment is small.

The ever growing complexity of railway as a system is imposing ever bigger demands regarding eployees’ skills, while working conditions and salaries are being stagnant compared to other areas of commerce. Traffic sector as a whole is lagging behind when it comes to integration of women. Also, it is necessary to take some action regarding the flexibility of workforce in order to overcome the inherent narrow profiling of employees stemming from the age of railways as a monopilistic companies. Further, a reduction of atypical working hours, better work contracts and generally better perception of jobs are considered as possible action for mitigating the lack of skills, by offering a better balance between social and private life for employees.

A special emphasis is on employees’ lack of skill, which should be resolved by providing focused (specialized) training and educational programs, as well as by employing talented and qualified workforce which should be ambitious and able to respond to railway sector’s challenges. In research projects in this field, great importance is given to identification of necessary skills and expertise concerning future jobs in railway sector. In integrated Europe, special attention is given to railway corridors, for which following actions are mentioned: modification of content for professional training (freight transport requires specific training), preparation of employment agencies to find more suitable places for employees, support for railway related employment platforms, identifying and supporting training possibilities for „sideline“ participants in transport chain, additional railway-related academic openings [6], [7].

Furthermore, the application of new railway-specific technologies will lead to diversification of employees’ tasks. As examples of new technologies which are also to be widely used by the railways too, are Internet of Things, artificial intelligence, robotics, remote monitoring, ERTMS. When it comes to „signalization“, it is observable that greater complexity of the system is heading towards the widening of employees’ skills. Constant growth and adaption to new technologies and equipment (e.g. more complex trains equipped with advanced electronics) in the area of „maintenance work“ affects the scope of employees’ skills and tasks. Research in the field of predictive maintenace and remote diagnostics is very intensive.

2.2 Technical and technological changes

In the field of technological changes, digital technologies have the leading role. Their utilisation facilitates:|

- the seamless monitoring of every phase of the life cycle of railway facilities and rolling stock,
- leads to an increase in the track capacities,
- contribute to increasing the safety of the railway lines and
- the availability of the railway system and its services (real-time monitoring of equipment and automated railway operations such as autonomous vehicles).

Digital technologies are focused on using the available and interoperable data. Gathering and managing this data is heading towards creating intelligent traffic management systems which support decision making based on proofs/facts and therefore increase overall performance of transport systems. This has the advantages for both internal system operations but also for traffic management between two and more transport systems [8], [9].

According to literature [2], [8], the technologies most mentioned are the following:

- Location technologies for the detection of train position as well as condition detection of railway infrastructure (e.g. for preventive maintenance).
- Internet of Things: rolling stock, infrastructure (including stations) and operations control systems are becoming fully

digitalized and networked components of the "Internet of Things". The ability to connect all elements of the rail system will lead to improvements in areas such as safety, security and predictive maintenance.

- Big data analytics: a more comprehensive knowledge of the environment (inside and outside the company) will improve both operations and the customer experience.
- 5G and beyond: The goal will be to maximise system coverage and its robustness and reduce physical infrastructures.
- Artificial Intelligence: Each element is provided with local artificial intelligence, which gives it the ability to perform targeted tasks with a high degree of autonomy [10] Artificial Intelligence enables the management of assets and operations under real-time conditions.
- BIM[1] and Digital Twin[2]: Reduced costs and improvements for all phases of the life cycle, from design to the end of lifetime of rolling stock and infrastructure [4].

- for design: improvement of modelling tools, better analysis of interactions between subsystems, better knowledge of the network.
- for maintenance: more precise knowledge of the equipment and its intensity of use, allowing maintenance to be optimised in terms of costs, delays (better planning of maintenance work) and resources.
- for the operator: The possibility to plan/reschedule the rotations; better analysis of complex incidents; greater reactivity and relevance of the decision in case of an incident

Better sustainability through optimized use of energy, increased reliability of system through its greater resistence, economical competetiveness through increased capacity, greater flexibility by adapting to the demand in real time are the advantages provided by automation and utilization of digital technologies. This presumes the development of advanced interoperable train control systems, introduction of advanced train management system (TMS), as well as the use of intelligent and autonomous vehicles and automation of logistics chain [2].

2.3. Environment and Politics

When it comes to environment and politics, two topics are the most present: green mobility and strategy of smart and sustainable mobility, and safety and harmonization of railway standards and regulations across Europe.

Because this megatrend is ubiquitous both in research and in public, we are emphasizing the following when it concerns the railways:

- Emission reduction is becoming the guiding issue of politics. Need for development of a wide array of complementary propulsion systems and types of fuel/energy for railway vehicles and infrastructure, as well as production and waste management (non-waste cycles) are currently urgent.
- Projecting, constructing, maintaining and utilizing the infrastucture able to resist climate changes.
- Reduction of noise and vibration caused by transport.

In question of mobility, it should be kept in mind that end-user needs have dramatically changed with introduction of new technologies. People are more connected by the day and they expect mobility services which are diverse, resistent, reliable, able to be selected by „pressing the button“, with completely transparent information and which are going in the direction of door to door mobility „by request“. Success of today's new transport models is, to great extent, based on their capability to fullfil these digital needs. For railways to remain the cornerstone of mobility, it is necessary to respond to all these challanges and improve their integration into new, all-reaching system of mobility. Railways can be a part of smart and sustainable mobility strategy by:

- improving digital connections and availability with all other forms of transport,
- developing the tools for appropriate interface management, which allows a combined reaction in case of incidents/disruptions,
- developing the elements of a multimodal transport management platform.

One of the biggest challenges which Europe is yet to overcome is its fragmentation into various networks with different sets of regulations and standars and different modes of railway operation. The planned Single European Railway Area and establishing of interoperable trans-European railway system can be used to promote the railway industry (railway supply industry-RSI) by creating a bigger demand. Combined with investment in the TEN-T core network corridors and in common European system of train control and communication in the form of ERTMS, will induce further development of European railways and the accompanying railway industry.

[1] *BIM – (Building information modeling) is a process involving genetarion and management of digital representations of physical and functional characteristics of places.*

[2] *Digital twin- refers to a digital replica of physical assets, processes and systems that can be used for various purpose.*

2.4. Economy and Markets

In this field, the importance of rail freight and passenger corridors is the most emphasized. Especially emphasized are the needs for:

- harmonisation and understanding of train control systems,
- the logistical management and operation of rail transport: providing knowledge and skills in the field of overall logistics management including rail technology and management (rail system, freight operations, management and technology required for the sustainable and intelligent design and operation of rail freight systems) [11].
- use of innovations and new ways of thinking based on the use of smart solutions, customer-oriented and adapted services.

Increased trade between Europe and Asia is further emphasizing the significance of existing and future (European) corridors.

To reach the full potential of railway systems, the necessity to adapt new technologies, interoperable solutions and optimized operations is particularly indicated. The topics above mentioned include: strategy and economy, operations and system performance capabilities, rolling stock, product qualification methods, safety and security, energy efficiency and infrastructure and signalization.

3. CONCLUSION

From desk research carried out in last ten years, it can be concluded that social changes, technical and technological changes, economic and environmental requirements are the key megatrends which affect the rail sector.

It should not be forgotten that mega- and micro-trends do not act separately, but influence and reinforce each other. For example, the use of new technologies, on one hand, results in the lack of qualified employees with the necessary competencies, but on the other hand, it has a positive effect on the reduction of emissions in railway traffic. Urbanization and environmental demands support the use of sustainable, intelligent, networked mobility systems and are therefore linked to further technology development. The harmonization and standardization of technical systems and the development of intelligent logistics management systems are essential to ensure intelligence in logistic management systems.

Without looking at the impact of these megatrends and, accordingly, identifying the necessary knowledge and skills that need to be incorporated into the curricula and programs of railway engineers, railways will not be able to fulfill the role intended for them in the European transport policy. Additionally, if railways want to catch up with the inland transport market, the implementation of new technologies on railways requires new skills and training of employed engineers.

The profound changes that have taken place with the liberalization of the railway sector require significant changes in the education and training of railway engineers. It is visible that they are late at this moment.

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SMALL RAILWAYS CHALLENGES IN THE SINGLE EUROPEAN RAILWAY AREA

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Abstract *– The establishment of the Single European Railway Aria (SERA) required pervasive and complex changes including restructuring of incumbents, the establishment of several regulatory authorities, the introduction of contracts between the government and infrastructure managers as well as passenger carriers, the introduction of railway infrastructure charges, etc. It required significant human, financial, organizational, and institutional resources. On the other hand, more than half of European railways belonged to the so-called small railways, which did not have the capacity for the required changes and, afterward, for managing a complex restructured railway system. The author's research ideas and criteria for "small railways" define the term small railways in Europe, discuss the specifics of the small railways and required resources, and the need to specifically explore models and solutions of small railways in the railway profession and science.*

Keywords – small railways, European railways, criteria, liberalization, capacity, capability.

1. INTRODUCTION

The creation of the European Union (EU) and the single European space required integration processes that, until now, were dominantly related to market liberalization and the erasure of national borders as obstacles to the movement, transportation of people, goods, and capital. European integration processes gained more momentum in the eighties and nineties of the past century. Trend of globalization in the world, gave this process additional "wind to the back".

Liberalization of the railway market was a big challenge for the EU. The previous national railway sectors were regulated as monopolies, so this change required great preparations and numerous major decisions. One of the biggest ones was restructuring national railway systems and railway incumbents companies. The EU started these processes on the railway in 1991 [1].

However, market liberalization and railway restructuring proceeded slower than expected in the atomized European space. Reasons for this should be sought, among other things, in the heterogeneity and disproportion in the size of the national railway systems and the large number of small railways (Figure 1). The restructuring and liberalization of the railway market in Europe are still ongoing and have not been completed.

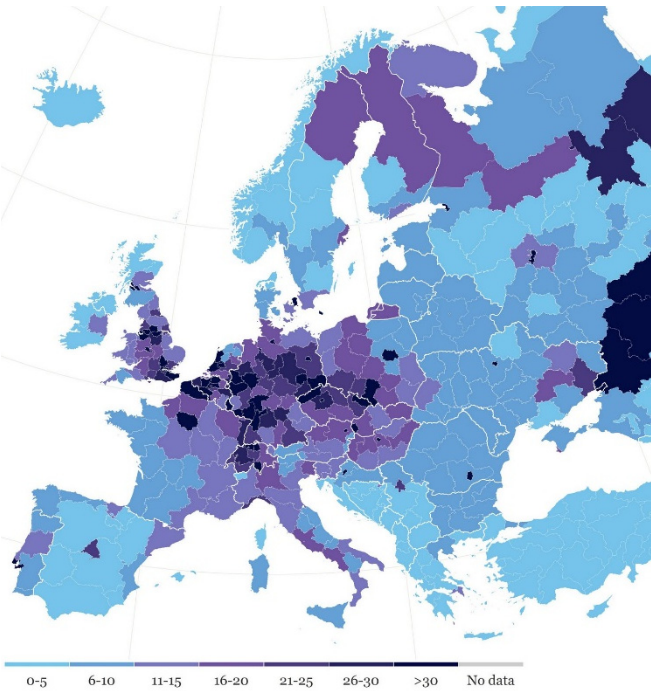

Fig. 1. The length of the track per 100 km^2 [11] as illustration of atomized Europeans railways space

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The term "small railway" refers not only to the size of the railway network and the national incumbent railway company but also to the resources of the state and society that can support and implement all the measures required by market liberalization. If we look at the map of Europe, that is, the map of European countries and their railway networks, then based on the size of the network alone, it can be estimated that more than half of the European countries have small railways [3,4].

After 30 years, it seems that the EU, while developing a Single European Railway Aria (SERA), set all the rules, solutions, and mechanisms without considering the capabilities and specificities of small railways. There are very few research projects about small railways' true capacities and strengths regarding restructuring, market development, and competition [4]. Additionally, there is a minimal number of papers in scientific journals related to the research of capacity and capability for the restructuring of small railways and states.

Can the European transport policy question the sustainability and survival of certain small national railways? Can they be adapted and follow the goals of the defined reform in establishing a single transport market? What are the effects of such reforms when only small railways are concerned, i.e., which railways benefited more from the reform (large or small)? There are just some of the questions that have not been analyzed so far.

In addition to the restructuring and liberalization of the market, significant other problems need to be solved (track access charges, public service obligation, managing of contracts, etc.) differently when it comes to small railways. However, primarily it is necessary to answer the question "*How to recognize a small railway?*" that is, what are the criteria based on which we can determine them?

This paper aims to define the criteria and discuss the surroundings which characterizes small railways, their capabilities, and strengths that determine a different approach to solving the listed tasks in creating SERA.

2. THE SURROUNDINGS AS A RESOURCE AND FACTOR IN SUPPORT OF THE SMALL RAILWAY REFORMS

Generally speaking, countries such as the countries of the former Yugoslavia, which are simultaneously in the process of transition and economic restructuring, are under the influence of a much larger number of factors in the restructuring process. In addition, we are talking about small economies on a global level and mostly small railways. As a result, the restructuring process becomes much more difficult, complex, and difficult to manage, and the primary reason for this is a scarcity of resources.

External factors of the railway environment such as the government's agenda, the scope and competitiveness of the economy, the dynamics of the implementation of technical-technological innovations, socio-cultural and other factors of a country, as well as international factors represent the framework in which the reform of a railway system takes place. This framework has a significant, even decisive, impact on the success of reforms. In the next part, to determine whether a railway is small, we will briefly discuss the key factors according to the type of environment [7,8].

Economic environment. When analyzing the objective, it is important to consider the following factors that largely determine the economic environment, such as gross domestic product, interest rates on capital, labor costs, inflation, fiscal and tax policy, and purchasing power of the population.

Social environment (socio-cultural factors). The social and cultural environment in which railway operates comprises attitudes, beliefs, desires, customs, expectations, social intelligence, and education of people in a certain geographical area. The elements mentioned above heavily influence societal awareness of the need for railways and societal attitudes toward railway reforms and their support.

Technological environment. Technology and technological innovations and their implementation are the key reason why the railway was successful in the past, and now it can be said that it is unsuccessful for the same reasons in today's time and age. Railways and railway companies that are not aware of the necessity of implementing new technologies and adapting their services to the increasingly demanding customers' needs have, as a result, a continuous decline in the share of railways in the transport market up to the level where they are forced to transport only goods wich have to transport by railways, such as the so-called bulk goods (coal, ores, construction materials, etc.).

Legislation of the railway system. The state determines the general and special economic conditions of business of all companies and regulates relations on the railway market with special railway laws. The state legislation defines the model, institutions, and criteria for regulating the transport market, establishing certain rights, obligations, and restrictions for all market participants. If conditions and relations are not well regulated or do not follow changes in society and the economy, then the legislation can become a significant limitation in terms of the position and competitiveness of railways in the transport market. Therefore, this criterion is also essential when determining whether a railway is small or not.

Ecological environment. Awareness of the need to protect the environment and related norms that discourage polluters and stimulate more efficient participants in the economy and transport also reflect society's capacity in logistical support of railways as the smallest land polluter in transport. Stimulating legal solutions are an unavoidable factor in the EU today. Therefore, the ecological environment is a criterion for defining the *capacity and capability* of a state in implementing environmental protection measures. In this regard, small states and societies generally do not possess capacities and human resources, which is reflected both in the competitiveness of the railway and in the requirements for solving certain problems, such as, for example, when designing the model of *track access charges.*

3. SMALL RAILWAYS - CHARACTERISTICS AND CRITERIA

In response to the question, what are the criteria by which a railway can be classified as a small railway, we will first state its characteristics, i.e., the essential features that distinguish it from large or medium-sized railways.

3.1. Characteristics of small railways

The railways of small countries have a resistance to change that is somewhat different from that of larger railways. The main reasons are [3,4]:

- their future is decided partially and inconsistently, i.e., from election to election and without development strategies;
- due to the lack of knowledge and capability about restructuring processes, business and technological processes are still connected to the traditional railway system (non-compliance of laws with sub-legal, internal and other acts);
- state-owned railway companies do not have the quality change management that can create and manage changes.

Characteristics mentioned above can be observed especially in closed railway markets, as is the case in the countries created by the breakup of the former Yugoslavia (Bosnia and Herzegovina, Serbia, Croatia, Slovenia, North Macedonia, Montenegro). These are the small railways where train routes are shorter, the intensity and volume of transport are small, and the quality and price of transport services are not acceptable for end users. Such conditions create fear by incumbents for opening the transport market and competition from private railway carriers.

Common to all small railways is that, in addition to the lack of capital and sources of financing, they also include a lack of qualified workers, a poor state of infrastructure, a lack of adequate managerial, marketing, and technical expertise, and very limited application of new technologies and technological innovations.

3.2. Railway classification criteria

In economics, the division of companies into small, medium and large is relevant for making decisions and their different treatment. In defining the classification criteria for small railways, we will also use the experiences from this field. The economic criteria for the classification of companies are the size, income, activity, etc. In practice in the same field, the classification of companies is done according to [5]:

- static criteria - determined according to the size of the company;
- functional criteria - determined according to the way of performing the transformational business process;
- institutional criteria - determined according to the legal form of organization of the company.

Considering the factors above and the characteristics of the railway, the criteria for categorizing railways as large or small are defined and described below.

Density the railway infrastructure network and its geographical position. These two elements have the greatest influence on the functionality of the railway network, especially as an important characteristic that determines its connection with the domestic and international economy and flow of goods and passengers. If the railway network has a density with the territory and economic centers, is adequately connected to neighboring railway networks, and is connected to the transport infrastructure of other transport modes than such network has greater logistical support and capacity for reforms. Small railways, such as B&H railways, are characterized by lower values of these factors (a low network density, a small number of flow conversion points between transport modes, and a small number of connections with neighboring railway networks and corridors).

Human resources capacities. Globalization in the world economy and its complexity has led to employees and their knowledge becoming the main resource of every state and its economic subjects. The railway, as a separate system with specific techniques and technology, requires specific knowledge from human resources. This is especially important in periods of system restructuring, incumbents and business processes. Small railways are characterized by limited access and the lack of human resources needed for the change. Also, investments in human capital and other business segments are minimal, as is the poverty of the environment for constant learning and improvement of various skills and knowledge of employees.

Economic indicators include the country's integration, trade openness, and gross domestic product. The greater the country's integration into economic flows and trade openness, the sooner one can expect a more favorable environment and resources, that is, capacities for reforms. Numerous indicators are used to measure and classify economic growth, the most common of which are macroeconomic aggregates summarizing economic activities, among which the gross domestic product is the leading indicator. Although it is a measure of production and not income, the gross domestic product is often used to approximate well-being or the population's standard of living. Ease of application and data availability made this indicator almost irreplaceable as a criterion.

Index of investments in the railway sector. Investments in the railway sector affect the country's entire economy, certain transport and operational costs are reduced, and it affects the increase in traffic safety. Investment policy, the efficiency of investments, and other indicators and their values show whether it is a small, medium, or large railway.

Institutional conditions. The state is an actor with a dominant influence on the success of the railway restructuring process. The implementation of EU guidelines and legislation and the development of a railway development strategy serve as both a foundation and a resource for improving railways. At the same time, the state-railway relationship requires radical changes and the transition to a contractual relationship in several areas. For all of the above, human and other resources are needed, which differ significantly between larger and smaller states, i.e., railways.

The state's role has changed significantly in the newly created conditions in Europe. The main role in developing the railway system and its restructuring belongs to the state, that is, the government. However, small countries and railways are still characterized by very scarce resources at the state level for the given role [2].

4. CONCLUSION

Due to limited resources, small railways necessitate a unique approach, model, and dynamics in achieving the goals of European transport policy and the establishment of SERA. This applies to all its elements, from the liberalization of the railway market and the restructuring of the railway sector, companies, and (contractual) state-railway relations to the modeling of track access charges and public transport obligations (PSO). Of particular importance is the possibility of developing new institutions in the railway sector (Regulatory Body, Safety Authority, Investigation Body, Licensing Body, Notified Body - NoBo, Designated Body - DeBo), and creating their authority is of particular importance.

Limited resources (human, professional, financial, capacity and quality of the railway network, research potential of the science sector in the domains of infrastructure maintenance, allocation of costs by place of origin, services, etc.), insufficient utilization of railway network capacity, inability to achieve efficient and effective competition of operators on the network, etc. . require a specific approach when it comes to small railways. The scientific and professional public has hardly studied this problem, even though it is estimated that small railways make up more than half of European railways.

For the mentioned criteria in defining whether a railway is small or not, in further research, it is necessary to define indicators and measures for the same, as well as (limit) values in specific European conditions.

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ASSESSMENT OF THE COMPETITIVENESS OF ŽRS ON THE REGIONAL RAILWAY MARKET OF THE WESTERN BALKANS

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Abstract *– The railway sector of Bosnia and Herzegovina (BiH) is facing the opening of the railway market. The restructuring of Željeznice Republike Srpske (ŽRS) is underway, and the holding structure is the intended model of the company's organization. Whether, and to what extent, the future company for the transport of goods will be competitive is one of the numerous questions and uncertainties brought by the liberalization of the railway market in Bosnia and Herzegovina. In the paper, the efficiency of the future operator for the transport of goods, ŽRS, was investigated in comparison with potential neighbouring competitors using the DEA method. Bearing in mind all the capacity limitations of the existing operators on the regional market, the DEA method was used to evaluate the efficiency of the historical r ŽRS ailway freight operator in comparison with the so-called historical operators in the Western Balkans region, with the aim of creating an objective picture of the needs for further development of competitiveness based on operator efficiency. According to the obtained results of the operator's current efficiency in the transport of goods, a discussion was held on potential requirements in terms of determining the needs for further development of the competitiveness of the ŽRS cargo operator on the liberalized railway market of BiH.*

Keywords - railway operator, efficiency, DEA model, Western Balkans, analysis of results.

1. INTRODUCTION

With the liberalization of the railway market, railway operators have moved from the stage of a safe market (monopoly) to the stage of fighting for the market. Consequently, this means that railway companies now, in the market, must constantly fight for greater efficiency of the company. Bosnia and Herzegovina (BiH) has not yet restructured the railway sector. The Željeznic**e** Republik**e** Srpsk**e** (ŽRS) are in the process of restructuring. This process foresees the independence of the part of ŽRS that deals with the transport of goods, so the question arises of its readiness for market competition with other railway carriers that will appear on the market. One of the most important measures of that readiness for the market competition is the efficiency of the company in comparison with other railway companies, as well as transport companies of other modes of transport. Drucker [1] believes that few things are as important to the success of a company as the measurement of business efficiency. Bearing in mind that efficiency in rail transport is affected by the use of time, space, vehicles, energy and personnel in the movement of goods, it is necessary to determine criteria for evaluating efficiency. One of the most commonly used methods for assessing relative efficiency is "data envelopment analysis" (DEA - Data Envelopement Analysis). In this paper, in order to take the necessary measures to increase the efficiency of the Railways of Republika Srpska, i.e. its current sector for the transport of goods as a future independent operator on the future regional transport market of the Western Balkans, the DEA method was used.

2. THE CONCEPT OF EFFICIENCY IN RAIL TRANSPORT

Efficiency is defined in many ways. There is no

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universal and general accepted definition of efficiency [2]. According to Kallur and Bhat [3], operational efficiency is defined as the ability of a business to make the best use of available resources to deliver quality products and services to customers.

Arvidsson [4] gave an overview of the definitions of efficiency in the literature, and he himself defined efficiency as a set of measures of the use of time, space, vehicles, fuel and drivers in the movement of goods. Operational efficiency depends on a number of factors such as the training and expertise of employees, technological improvement, optimal procurement and control of supply chains, etc.

In the following, we list several examples where various authors dealt with efficiency in the railway market. Pavlyuk [5] in his study "Analysis of the efficiency of the railways of European countries", uses stochastic frontier analysis to evaluate the efficiency of the railway system in European countries. To determine the degree of efficiency of the railway system, it uses various parameters (length of operational routes, number of traction vehicles and cars, employees and scale of the market, etc.). The result of the research showed that railway systems show huge differences in technical efficiency between different countries, as well as between freight and passenger transport within the same country.

business in the railway sector. In a narrower sense, the subject of the research focuses on the notion of a railway operator through the development of a model for determining the efficiency of railway operators, especially in the process of restructuring the railways of the Western Balkans conditioned by the need to increase economic efficiency.

3. DEFINING CRITERIA FOR ASSESSMENT OF EFFICIENCY

The selection of criteria for the efficiency of railway operators is a very complex process and belongs to the domain of strategic planning.

In the process of defining the model for evaluating efficiency, it is necessary to look at and define the criteria that influence the efficiency of the railway operator. In order to define and evaluate the criteria, research was carried out on the most frequently used criteria for the efficiency of railway companies from the available literature. According to the literature [8] [9] [10] [11] i [12], in which the focus is on operators for the transport of goods, a number of different criteria were used (table 1). For research in this paper, based on the analysis of review papers, the following criteria were selected, which will be used as input in the DEA method: (1) network lengths, (2) number of locomotives, (3) number of freight cars and (4) number of employees, while the criterion of the achieved volume of work (5) which is expressed in NTKM will be used as an output in the DEA method. Table 2 shows the criteria values of the operators of the Western Balkan countries for the period from 2017 to 2021, which will be used to calculate efficiency using the DEA method. In the next part, the above mentioned criteria will be briefly explained.

Table 1. Literature describing operator efficiency

Authors	Title of work	Method	Come in	Get out
Valeria Maltseva, et al. (2020)	Efficiency Analysis of Russian Rail Freight Transportation Companies with Super Slack-Based Measurement Data Envelopment Analysis	Super slack-based measurement (SBM), Data envelopment analysis (DEA)	1) Number of railway vehicles 2) Number of employees	1) tkm
Marchetti and Wanke (2017)	Brazil's rail freight transport: Efficiency analysis using two-stage DEA and cluster-driven public policies.	DEA CCR / BCC Bootstrap truncated regression	1) Number of trucks 2) Number of employees	1) tkm 2) TKU
Miloš Milenkovic, et al. (2016)	Analysis of the Efficiency of European Railway Companies with Special Focus on the Czech National Railway Company	SFA and DEA	1) Number of trucks 2) The length of the network 3) Number of employees	1) tkm
George and Rangaraj (2008)	A performance benchmarking study of Indian Railway zones.	DEA RCCR	1) Operating costs; 2)Traction force; 3) Car km; 4) Number of employees; 5) Number of passenger cars; 6) Number of trucks	1) pkm 2) tkm
Cantos and Maudos (2001)	Regulation and efficiency: the case of European railways.	DEA	1) Number of trucks; 2) Number of employees; 3) The length of the network	1) pkm 2) tkm

Ehrmann [6] points out that the deficit of state railways is huge and that the question of the efficiency of companies has become topical in economic and political debates. At a time when there is a large public debt all over the world, the state has a natural interest in railway companies adapting and making the capital allocated to them profitable. Cowie [7] uses DEA to compare the efficiency between private railways and public railways companies in Europe.

The subject of research of this paper arises from the need of the countries of the Western Balkans, whether they are members of the EU or applying for membership, to establish market principles of

The criterion of the length of the network (1) and its shape affects the efficiency of the railway operator with its characteristics such as network branching, connection of individual network segments with nodes and terminals, as well as connection with neighboring networks.

Table 2 - Operator criteria for the period 2017-2021.

		2017	2018	2019	2020	2021
HDL*	k1	423	423	423	423	423
	x2	55	55	55	55	55
	x3	537	537	537	537	537
	x4	1880	1880	1880	1880	1880
	x5 (10^3)	460	460	460	460	460
ŽFBH	k1	601	601	601	601	601
	x2	97	97	97	97	97
	x3	2167	2174	2174	2174	2174
	x4	3229	3162	3162	3200	3200
	x5 (10^3)	730000	806710	807000	807000	808000
ŽRS	k1	417	417	417	417	417
	x2	71	71	71	71	71
	x3	2067	2063	2063	2063	2063
	x4	2740	2482	2252	2 184	1988
	x5 (10^3)	38 6405	371612	403902	363285	380429
MŽ - TRANSPORT	k1	683	683	683	683	683
	x2	43	42	42	42	42
	x3	1011	1289	1289	1289	1289
	x4	1300	896	896	900	900
	x5 (10^3)	423000	307160	307000	307000	307000
MONTE CARGO	k1	239	239	239	239	239
	x2	11	11	11	11	11
	x3	561	561	598	598	598
	x4	1000	360	360	355	354
	x5	159950	168900	169000	169000	130000
SERBIA CARGO	k1	3736	3736	3736	3736	3736
	x2	183	183	183	79	79
	x3	6781	6781	6781	6527	6527
	x4	3250	3248	3248	3240	3240
	x5 (10^3)	3288000	2790400	2790000	3055000	3055000

*in the UIC statistics there is information only for 2017.

The basic characteristic of the BiH railway network is that it is not branched. Also, it has a low density compared to the surface of the earth. The density of the network is significantly reflected in the accessibility and availability of the railway service.

The available number of rolling stock (3) and (4) is one of the key criteria for the competitiveness of railway operators on the open transport market. For the railway operator, it is of particular importance to achieve optimal use of capacity, which implies such use of rolling stock that will achieve the relatively most favorable relationship between the consumption of their useful properties, on the one hand, and their production performance, on the other. With the liberalization of the market, the competition between operators is stronger, both in terms of volume and quality of transport services. Therefore, it is very important to have modern vehicles. Today's two operators in Bosnia and Herzegovina have a very old fleet with high maintenance costs. In the conditions of a liberalized market, low business costs have a decisive impact on competitive advantage. Therefore, the number of employees (4) represents a key component of the efficient business of railway operators. Fixed and operational costs of business are under increasing pressure and mostly show growth trends. Railway operators are by their very nature a labor-intensive industry, which means that one of the main drivers of costs is the cost of employees.

On the other hand, there is an increasingly present deficit of workforce that has the knowledge and experience needed to apply new technologies that find their implementation on the railways. With the beginning of the restructuring process in ŽRS, there is a noticeable trend of a decrease in the number of employees, which indicates the gradual adaptation of this operator to the market conditions of business and adaptation to real needs.

The scope of the performed service represents the output result and is expressed in net ton kilometers. In combination with the number of vehicles, it indicates the efficiency of their use. It has a great impact on the overall efficiency of railway operators' operations.

4. A MODEL FOR ASSESSING THE EFFICIENCY OF RAILWAY OPERATORS

The problem of measuring the efficiency of railway companies is apostrophized in the literature as the problem of measuring the efficiency of multi-phase (multi-stage) processes. The most commonly used method for evaluating the efficiency of multiphase processes is Data Envelopment Analysis or DEA (Data Envelopment Analysis) method. In the literature there is a whole spectrum of efficiency evaluation models based on DEA models. It can be said that the use of the DEA method in the analysis of the efficiency of companies no longer needs to be explained, and it is not necessary to present the method itself. Therefore, below, only the stages of its use will be briefly presented. The model used in this work was tested and verified through research conducted on a sample of 5 railway operators of the Western Balkan countries for the transport of goods. CCR and BCC models were used to determine the efficiency of the operator for transporting goods. In the paper, the evaluation of the efficiency of railway operators was carried out based on input and output parameters and using the DEA "excel solver". The results of the efficiency of freight transport operators for the period 2017-2021 are shown in table 3. The data source for operators was used from UIC statistics and annual reports of railway operators. A railway operator for the transport of goods as a DMU is determined by four inputs and one output (Figure 1).

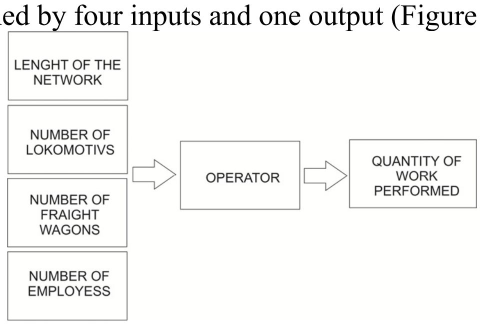

Fig. 1. Railway operator as DMU for efficiency assessment

Table 3. Evaluation of the efficiency of operators for the transport of goods

		Eff 2017		Eff in 2018		Eff in 2019		Eff in 2020		Eff in 2021	
		CCR	BCC	CCR	BCC	CCR	BCC	CCR	BCC	CCR	BCC
DMU1	Albania-HSL	0.0018	0.0018	0.0021	0.0021	0.0021	0.0021	0.0018	0.0018	0.0018	0.0018
DMU2	BiH - ŽFBiH	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DMU3	BiH (RS) - ŽRS Kargo	0.7581	0.7581	0.0661	0.0661	0.6608	0.6608	0.6537	0.6538	0.7133	0.7134
DMU4	Macedonia-MŽ-Transport	0.8628	0.8629	0.5831	0.5831	0.5829	0.5829	0.5238	0.5238	0.5238	0.5238
DMU5	Montenegro-MonteKargo	0.8092	0.8093	1.0000	1.0000	1.0000	1.0000	0.7664	0.5896	0.7663	0.5898
DMU6	Serbia-Serbia Cargo	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

5. ANALYSIS OF RESEARCH RESULTS

Based on the obtained results, we have 2 operators that have a value of 1, and they are considered efficient compared to the others.

It can be seen from the table that the most efficient operators are "Srbija Kargo" and ŽFBH, while the operators HSL, MŽ Transport, Monte Cargo and ŽRS (Kargo) are inefficient.The efficiency of ŽRS (Cargo) is decreasing, with the fact that it is visible that in 2021 growth occurs. The reason for the increase in efficiency and competitiveness of this operator is the increase in the volume of transportation and work performed, the constant reduction in the number of employees, as well as adaptation to the market conditions of business. Also, it is evident that in the period 2017-2018 only the operator in Albania (HSL) has a worse result than the operator ŽRS. From 2019 ŽRS raises the level of efficiency, with the exception of 2020 which, due to the corona virus, stopped this growth trend, which continued in 2021 when ŽRS is just behind ŽFBH and Serbia Cargo in terms of efficiency. The results show that with the other operators of the Western Balkan countries, the efficiency of operations decreases as time goes by (Monte Kargo and MŽ-transport). The above shows that those operators who are ready to enter the open market sooner will have an advantage over the others.

6. CONCLUDING CONSIDERATIONS

Measuring the efficiency of railway operators in the future will be a necessity for them if they want to maintain their competitiveness and positions on the open transport market. After the opening of the market and the entry of private operators, it is inevitable that the historical operators, including ŽRS, will lose part of the market. In order for ŽRS to continue with the trend of increasing efficiency and become a competitive operator that could compete with more efficient operators in the countries of the Western Balkans and beyond, it is necessary to find additional quantities of goods for transportation, and continue with the processes of restructuring and solving the inadequate structure of employees, as well as with the procedures for dealing with outstanding assets and funds that additionally burden the operator ŽRS Kargo. Investments and investments in rolling stock are needed, in order to reduce depreciation and maintenance costs and in the future period of market liberalization to be able to cope equally with other operators. Raising the level of technical and technological development at ŽRS is also one of the measures to increase efficiency.

All of the above indicate that the railway operator ŽRS Kargo for transport in Bosnia and Herzegovina must raise its efficiency to an even higher level in order to be competitive with other railway operators on the transport market.

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OPENING OF THE RAILWAY SERVICES MARKET IN THE REPUBLIC OF SERBIA

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Abstract *– In order to increase efficiency and achieve market-oriented and competitive railway freight and passenger transport, after almost a hundred years of functioning of the railway sector on the principle of national railways, a long and extremely demanding reform process in the European Union has resulted in market opening and providing access to railway infrastructure for all railway undertakings that meet the legal requirements. The railway market in Serbia was legally opened to railway undertakings based in Serbia in 2005 thanks to the harmonization of the national railway legislation with the relevant EU regulations and adoption of the Law on Railways that provided for the possibility of new entrants in the railway transport market. However, we can say that it was not until 2015, after the separation of the integrated railway company "Železnice Srbije ad" in accordance with the acts of the Government of the Republic of Serbia establishing three new railway companies, that the railway market in Serbia was actually opened. Thus, in 2016, after the publication of the first Network Statement by the infrastructure manager, the first new entrant gained access to railway infrastructure and since then the process of liberalization of the railway market has been unstoppable. Therefore, today there are 24 licensed railway undertakings in Serbia, one of which is for passenger transport, 18 for transport of goods under market conditions and 5 railway undertakings transporting goods for their own needs. Since its foundation, the Directorate for Railways has had a key role in the establishment and functioning of the railway market, in accordance with its legal competencies in the capacity of entity that issues licenses and certificates and in the realization of its regulatory function by enabling non-discriminatory access to infrastructure. In accordance with the transitional periods defined in the Transport Community Treaty, the railway market in Serbia is open to competition at the national level. As part of the further realization of obligations from the Transport Community Treaty, the opening of the railway market for international rail passenger and freight traffic will follow, first at the regional level, and then between Serbia and EU countries.*

Keywords – railway market, market opening, railway services, licenses, railway undertakings.

1. INTRODUCTION

Due to the permanent lagging behind of the share of railway transport in the total transport of passengers and goods, railway sector required a thorough restructuring with the introduction of competition as a basic market mechanism for improving the efficiency of operations in all economic branches, including in transport. In order to introduce competition, the doors of the railway services market had to be opened, which happened in the railway sector after almost a hundred years of functioning according to the principle of national railways that practically meant identification of the state and railways. Namely, the comfort of being protected under the "wing" of the state led to a general lethargy in the railway sector in all European countries, which resulted in a constant weakening of the role of the railway in the transport market. Therefore, its share in the transport of passengers and goods fell low at the end of the 20th century, despite its traditional advantages in the field of ecology and safety. The harsh laws of the market do not tolerate passivity, so the development of the railway sector needed a new approach and guidelines in order to move from a century-old monopoly position to a market oriented way of doing business. The European Union took up this historic task and passed a series of regulations in the field of railway law starting from 1991 and the first reform directive of the EU. Its imperative

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was to separate infrastructure management (IM) from transport in order to achieve today's market oriented behaviour of railway undertakings in accordance with the key directive in this field, Directive 2012/34 on the establishment of a single European railway area.

2. LEGAL FRAMEWORK FOR MARKET OPENING IN SERBIA

The opportunity for new entrants in the rail transport market was created by the adoption of the Law on Railways ("Official Gazette of the RS", number 18/05), which was the first step in the harmonization of national railway legislation with the acquis of the European Union in the railway sector. This law established the legal framework for the opening of the rail transport services market and provided access to the use of the public railway infrastructure under equal conditions for all interested operators who meet the requirements prescribed by the law. This law, among other things, represented the founding act of the Directorate for Railways and prescribed the basic competencies of the regulatory body that related to issuing decision upon complaints in case of rejected or amended offer for the conclusion of contract on the use of the railway infrastructure. Further harmonization with EU railway legislation was achieved by the Law on Railways adopted in 2013, amended in 2015 and 2017, and the Law on Railways from 2018 ("Official Gazette of RS", number 41/18), which is currently in force. The railway market in Serbia has been legally open to railway operators based in Serbia since 2005, but it was actually opened only after the unbundling of the integrated railway company "Serbian Railways" a.d. In July 2015, the Government of the Republic of Serbia adopted founding acts for three new companies, "Srbija Voz" a.d, "Infrastructure of Serbian Railways" a.d. and "Srbija Kargo" a.d.

Directive 2012/34/EU (amended by Directive (EU) 2016/2370 and Commission Delegated Decision (EU) 2017/2075) foresees the possibility of a holding organization under certain conditions, however, Serbia implemented a complete separation of activities related to IM, passenger and freight transport. In addition to all of the above, without equal access to relevant and updated information about the network and access conditions, it was not possible to establish and operate the railway services market under equal conditions. Therefore, Network Statement was an indispensable document, i.e. a key document providing quality information about the network and ensuring the same level of information to all interested railway undertakings, taking into account the fact that the incumbent freight and passenger railway undertakings already had information about to the network. The network statement brings together all relevant information about the railway infrastructure on the network as well as commercial and legal conditions for access. The obligation of the IM to publish the Network Statement was established for the first time in the EU by the adoption of Directive 2001/14EC. Directive 2012/34/EU introduces the obligation of the IM to publish the Network Statement in at least two official languages of the Union and make the content of this document available free of charge in electronic form on its web portal. In the Republic of Serbia, the adoption and publication of the Network Statement is a legal obligation of the IM. The IM published the first Network Statement in the RS in 2016. The same year, the first new entrant gained access to the railway infrastructure. Since then, the IM has regularly published the Network Statement and thus continued to enable access to the railway infrastructure of all interested operators that meet the prescribed conditions. In the closest connection with the Network Statement, for the smooth functioning of the market of railway services, it is necessary to establish an independent body, i.e. institutions with the task of ensuring fair and non-discriminatory access to railway infrastructure. In the Republic of Serbia, the function of the Regulatory Body is performed by the Directorate for Railways, a special organization with the status of a legal entity, established by the Law on Railways in 2005. From the initial task of deciding upon complaints against rejected or amended offers for the conclusion of contracts on the use of railway infrastructure, its competences have been expanded many times within further harmonization of national legislation with EU regulations and the adoption of the Law on Railways in 2013 and 2018. Therefore, today we can say that the Directorate for Railways almost completely performs the function of the railway regulatory body. The planned path of development and improvement of railway transport implies activities related to the integration of the railway network and opening of the railway market at the European level, including countries that are not members of the EU. For that reason, there was a need to institutionalize regional cooperation among countries of the Western Balkans, i.e. the countries of South-Eastern Europe.

Regional cooperation and cooperation with the EU in the field of rail transport was first organized through the Transport Observatory for Southeast Europe - SEETO, and then through the Transport Community Treaty. The Treaty was signed by the European Union and six partners from Southeast Europe: the Republic of Albania, Bosnia and Herzegovina, the Former Yugoslav Republic of Macedonia, Kosovo[*], Montenegro and the Republic of Serbia, between 12 July in Trieste and 9 October 2017 in Brussels. It entered into force on 1 May 2019 in according to its Article 41(2). All parties have ratified or approved it. The goal of the Transport

[*] *This designation is without prejudice to positions on status, and is in line with UNSCR 1244 (1999) and the ICJ Opinion on the Kosovo declaration of independence*

Community in the field of rail transport is the progressive integration of the transport markets of South-Eastern European countries into the transport market of the European Union. This should be realized in phases through transitional periods starting with the opening of the market at the national level, then at the regional level and finally by integration into the EU market. The progress of each party to the Treaty from Southeast Balkans in the mentioned stages is evaluated in accordance with the prescribed rules, and the evaluation is carried out by the European Commission in cooperation with the respective party from Southeast Europe. In addition, the European Commission regularly assesses the progress of railway reforms and encourages further development of railway transport through international market opening and strengthening the role of regulatory bodies and their administrative capacities.

3. RAILWAY SERVICES MARKET OPENESS IN THE REPUBLIC OF SERBIA

Given that improving the quality of railway services and strengthening the competitiveness of railways as a mode of transport is the key reason and goal of the entire reform of the railway sector, it was necessary to open the market and ensure fair competition, for which the Republic of Serbia invested enormous efforts and carried out numerous activities. The adoption and publication of the first Network Statement in 2016 gave green light for new entrants into the railway market that opened its doors at the national level.

The first rail transport license and safety certificate for freight transport were first granted in 2007. However, the conditions for access to the infrastructure by all economic entities that already met all the conditions, i.e. had a rail transport license for the transportation of goods, a safety certificate and the possibility to conclude a contract on the use of the infrastructure, were created only in 2016. Since then, access to railway infrastructure by private operators has been steadily growing.

Today, in the Republic of Serbia, 23 railway undertakings have a freight transport license, of which 18 undertakings have a license for commercial transport and 5 of them transport goods for their own needs. Only one railway undertaking (incumbent) has a licence for passenger transport. Out of 24 licensed undertakings, 14 undertakings have safety certificates part A and B and they operated on the public railway infrastructure in 2021. In 2021, in addition to the incumbent undertakings "Srbija Kargo" a.d. and "Srbija Voz" a.d, public railway infrastructure in 2021 was used by another 12 private railway undertakings (3 of which transported goods for their own needs).

The following chart shows the periodic growth of the number of railway undertakings that held a rail transport license in the period from 2014 to 2021:

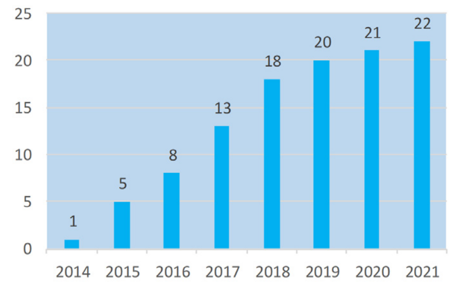

Fig.1. Number of licensed railway undertakings

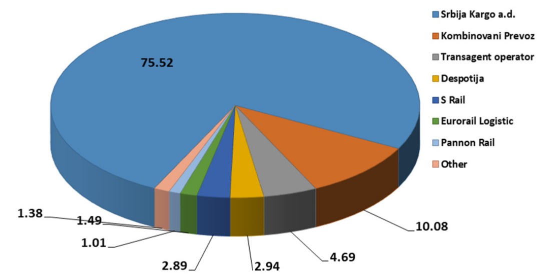

Fig.2. Share of railway undertakings in the railway market in percentage of gross tonne km in 2021

The following chart shows the share of private freight railway undertakings in the period from 2018 to 2021:

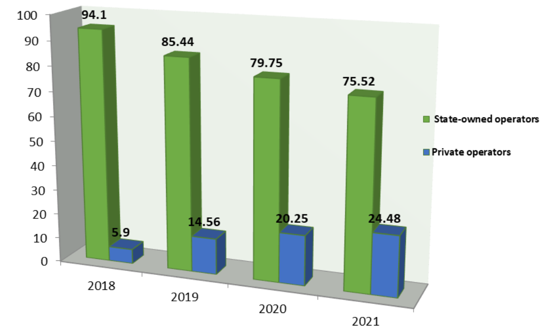

Fig.3. Share of private undertakings in the railway freight transport market from 2018 to 2021

Based on what has been shown, we can say that the share of state-owned railway operators in freight transport continues to decline in favour of private operators. Namely, the share of private operators in the market of railway services according to gross tonne kilometres increased from 20.25% to an already significant 24.48% in 2021 compared to 2020.

Although the number of new entrants on the rail freight market grew in the period from 2019 to 2021, according to the data collected by the Statistical Office of the Republic of Serbia, the share of rail transport in relation to road transport did not increase, but decreased in the same period. This means that opening up the rail market to competition is not even nearly enough to make rail competitive with other modes of transport, especially road transport. Therefore, much more needs to be done in order to increase the capacity of the railways and achieve a more competitive, efficient and user-oriented railway transport in Serbia. However, it should be noted that the decline in the share of railways in the market in 2019 and later is related to the extensive works on the railway infrastructure, which largely influenced the orientation of users towards other types of transport in Serbia in 2019 and after that. The railway services market in the Republic of Serbia is open to private operators in both freight and passenger transport, but there is only one national operator that participates in passenger transport so the share of the incumbent undertaking in passenger transport is still 100%. The graph below shows the data on the share of transport based on PSO (public service obligation) in relation to the share of transport outside PSO.

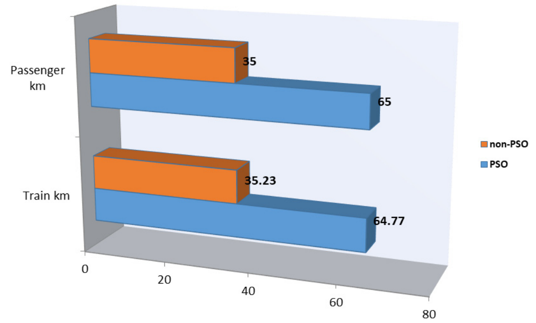

Fig.4. Total share of transport based on PSO

On the basis of the graph, it can be noted that the share of transport based on PSO in the Republic of Serbia is significant, as well as that the majority of passenger transport is carried out on the basis of PSO. However, if we compare the share of train and passenger kilometres based on PSO in the previous year, it can be noted that the share of transport performed on the basis of PSO is in decline, considering that in 2020 it amounted to 76.76% (train kilometres), i.e. 87.85% (passenger kilometres). The following graph shows the share of transport based on PSO, taking into account only domestic traffic, while international traffic takes place exclusively outside PSO.

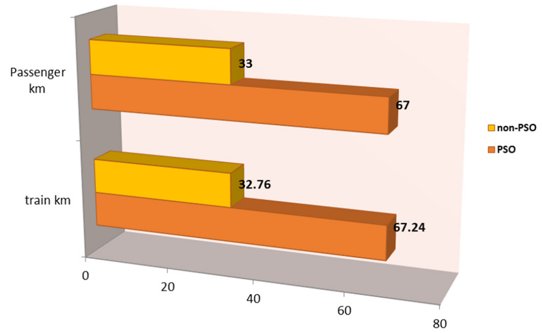

Fig.5. Total share of transport based on PSO in the national transport

The following graph shows the total number of transported passengers in domestic and international traffic for the period from 1 January 2018 to 31 December 2021.

Based on the graph, it is noted that the pandemic of the disease COVID-19 additionally affected the negative trend, i.e. decrease in the number of transported passengers. Passenger transport services were used by a total of 2.7 million passengers in 2021, which is about 40% less compared to the period before the pandemic, i.e. to 2019, with a slight increase being observed when comparing 2020 and 2021 and, therefore, in 2021, an increase of about 6% in the number of transported passengers was recorded compared to 2020.

4. CONCLUSION

Bearing in mind the presented situation in the field of the openness of the market of railway services in the Republic of Serbia, i.e. the analysed results of its openness, we conclude that much more significant changes are inevitable in the railway sector than those already implemented. Those changes should tackle both the aspect of the revitalization of railway transport and its integration in the Single European Railway Area, that is, accession to the European Union.

In accordance with the transitional periods defined in the Transport Community Treaty, the railway market in Serbia is open to competition at the national level. As part of the further realization of the obligations from the Transport Community Treaty, the opening of the railway market for international rail passenger and freight transport will follow, first at the regional level, and then between Serbia and the EU countries. One can still hope that railway transport, recognized as one of the most environmentally friendly modes of transport, will succeed in achieving the goal of the European Green Deal. The main objective is to increase the participation of railway transport in total land transport (75% of land freight traffic that is today performed by road should be transferred to railways and inland waterways) and thus contribute to a climate-neutral European Union by 2050.

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XX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
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DEFINITION OF STRATEGICALLY ORIENTED TRANSPORT USERS IN FREIGHT TRANSPORT AT RSR

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Abstract *– User of transport services is company or person who, based on contract signed with the carrier, acquires certain rights and assumes certain obligations. The task of the railway company is to meet the needs of service users, the economy and society as a whole, in terms of passenger and cargo transport. If the services and their quality meet the user's demands and the prices are stimulating, it will provide a satisfactory sale of services, as well as the capacity utilization. This paper deals with analytical processing of existing and potentially important users of transport in order to create a basis for consideration of the economic interest of the railways.*

Keywords – transport user, transport contract, quality of service.

1. INTRODUCTION

The restructuring of railways requires the transport of goods to be prepared for an independent and sustainable business in the transport services market.

So far, the railways have provided practically two types of commercial concessions for all users at approximately the same or similar level, without taking into account how much each user has invested to carry out rail transport and how big their strategic commitment to rail transport is.

The existing commercial policy of Republika Srpska Railways (RSR) jsc. Doboj defines the use of a single commodity tariff and the approval of certain concessions. The commercial concessions which were granted to all users in the freight transport have been permanently changed over the years, regardless of their commitment, readiness, organization and investment in the development of their own capacities for rail transport.

In the commercial terms, the tariff policy of the railways must create an environment to attract new users, as well as permanently ensure an increased volume of transport from year to year, thus creating the conditions for further development of freight transport activities.

2. COMMERCIAL CONDITIONS FOR TRANSPORT USERS OF REPUBLIKA SRPSKA RAILWAYS

The transport user is a legal or natural person who, based on the contract with the carrier, acquires certain rights and assumes certain obligations. [1]

The carrier is the railway company with which the passenger or the consignor of the goods concludes a contract of carriage.

The contract of freight carriage obliges the carrier to transport the freight to the destination station and hand it over to the consignee, and the consignor undertakes to pay the carrier the agreed charge for the transportation (carriage charges).

The consignor may subsequently amend the contract of carriage, thereby requiring the following from the carrier:

- To stop transporting the freight further;
- To postpone the delivery of the freight;
- To hand over the freight to another entity, and not the consignee referred to in the consignment note;
- To hand over freight in another place, and not the place referred to in the consignment note.
- To establish the carriage charge for this wagon based on the price table for the tare

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wagon reduced by 50 %.

3. DEFINITION OF A STRATEGIC ORIENTED TRANSPORT USERS AND THE CRITERIA FOR THEIR DETERMINATION

3.1. The evaluation of significance of certain transport users

Implementing a selective railway policy in relation to transport users means finding possible measures to provide better conditions to individual service users which are strategically oriented towards railway transport – the strategically oriented transport users, in relation to their overall importance for railway operations. [2]

The determination of priorities in terms of granting certain advantages to individual users of services implies conducting a preliminary study of all significant transport users, both existing and potential. For the railways to be in a position to perceive its long-term interests when it comes to its users, it is necessary to analyze the data on the volume of transport for all the users or the overall volume of operation performed for the purpose of the transport users as a whole.

The analysis of the importance of individual transport users is based on the following fundamental criteria:

- Total number of transported tons of freight;
- Earned revenues from the transport users.

An assessment of their importance may be obtained by applying these criteria to each individual transport user.

3.2. Classification according to the total number of transported tons of freight

The classification of transport users can be carried out according to the criterion of the total annual volume of operations (the number of transported tons of freight), expressed in tons.

According to this criterion, the five categories of transport users were established with the following annual volume of operation (table 1):

Table 1. Classification of transport users according to the realized operations

1. category	over 500,000 tons
2. category	100,001 – 500,000 tons
3. category	10,001 – 100,000 tons
4. category	1 – 10,000 tons
5. category	0 tons (no operation)

The number of categories has been selected on the basis of long-term research of operation with the transport users. The categorization defined in this manner reflects well the differentiation of transport users according to the scope of operations.

3.3. Classification according to the overall revenues from the transport users

The classification of transport users may be carried out according to the criterion of total annual revenue, expressed in convertible marks (BAM). Five categories of transport users with annual revenue earned to RSR jsc. Doboj were established according to this criterion (table 2):

Table 2. Classification of the transport users according to the revenues earned to RSR jsc. Doboj

1. category	over 1.000.000 BAM
2. category	100.001 – 1.000.000 BAM
3. category	10.001 - 100.000 BAM
4. category	1 - 10.000 BAM
5. category	0 KM (no operation)

The number of categories has been selected on the basis of long-term research of operations with the transport users. Such a defined categorization reflects well the differentiation of transport users according to the revenues earned to RSR jsc.

3.4. Definition of strategically oriented transport users

The existing commercial policy of RSR jsc. Doboj defines the use of a single commodity tariff and the approval of certain concessions. The commercial concessions which were granted to all users in freight transport have been permanently changed over a number of years, regardless of their commitment, readiness, organization and investment in the development of their own capacities for rail transport.

In regards to the tariffs and commercial affairs, the same principles apply to all users, which should not be the case in the coming period, especially when it comes to the wagon demurrage, which is practically a penalty for the largest customers in situations where they have emergency (unloading capacity defect, strike, low temperature, etc.).

So far, the railways have provided practically two types of commercial concessions for all users at approximately the same or similar level, without taking into account how much each user has invested to carry out rail transport and how big their strategic commitment to rail transport is. These concessions are the following:

- Commercial concessions for a certain annual quantity of goods (20 - 30%);
- Tariff concessions for block trains and groups of wagons (10 – 20 %). [3]

The structure of revenues in freight traffic generally consists of:

- Revenues from strategically oriented transport

users;
- Revenues from other transport users;
- Transit revenues. [4]

The abovementioned division implies that the commercial policy measures of RSR jsc. Doboj should not be the same for all listed users.

In commercial terms - the tariff policy of railways must create an environment for attracting new users, as well as permanently ensure an increased volume of transport from year to year, thus creating the conditions for further development of freight transport activities.

Should the tariff and commercial conditions be changed, the users of transport would try to redirect the goods that were transported by road until now to the railways.

In the coming period, the railways must improve at all levels, that is, the level of quality of transport services, in order to obtain new quantities of goods from strategically oriented transport users. The quality of freight transport services consists of the following elements:
- Speed of freight transport and delivery period;
- Regularity of transport;
- Method of ordering and delivery of wagons, time and method of loading and unloading;
- Information about the consignment movement;
- Characteristics of transport capacities;
- Transport safety. [5]

3.5. 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.

By using this analysis, the company can identify its main advantages (strengths) and disadvantages (weaknesses), what the opportunities (chances) and limitations (threats) are in the realization of its goals. [2]

The ultimate goal of the SWOT analysis is aimed at determining the strategic position of the company and choosing a development strategy which can be adequately implemented.

When implementing this analysis, the advantages and disadvantages refer to the company, i.e., to the resources it has in relation to the competition and to the users of transport services, while the opportunities and limitations refer to external factors affecting the transport company.

The advantages refer to zones of noticeable success, while disadvantages refer to zones of failure of a company. The chances refer to environmental trends with positive outcomes, while threats refer to environmental trends with potentially negative outcomes. Naturally, the goal of a company is to make the most of its strengths and opportunities, and to minimize its shortcomings and limitations. [1]

The analysis procedure is as follows:
- Identification of strengths, weaknesses, opportunities and threats;
- Classification according to importance and probability of occurrence;
- Analysis of the interrelationship of opportunities with strengths and weaknesses, as well as threats with strengths and weaknesses;

Table 3. SWOT analysis for RSR jsc. Doboj in the field of transport and relationship with the transport users

Strengths • the existence of the transport market – actual demand for transport services, • large transport capacity, • price competitiveness - potentially low transport costs, • preservation of the environment, • saving energy, i.e., liquid energy sources, • safety, • available staff.	**Weaknesses** • technical - technological obsolescence of capacities, • low quality of transport service, • shortage of wagons and locomotives (great immobilization), • high total and fixed operative costs, • inadequate cost monitoring, • insufficiently adapted work organization to market business conditions, • poorly designed marketing and promotion.
Opportunities • more flexible formation of prices and concessions, • social reforms and potential economic and regional development, • approval of international loan institutions for investment in development of railways, • increase in cartage/delivery capacity, • the possibility of introducing modern transshipment techniques.	**Threats** • greater flexibility and quality of road traffic service: - speed of transport by road traffic, - door-to-door truck delivery, - price policy ″by agreement″, • slowness of reforms and restructuring, • large locational dispersion of transport users.

- Identification of strategic alternatives. [2]

The relationship between railway and road transport, as well as the existing competition, requires special analysis and, based on them, special measures, which will significantly redirect goods to railway traffic. [1]

In order to make good use of all the advantages of rail transport for transport users, it is necessary to look at strengths and weaknesses (internal analysis) and opportunities and threats (external analysis). These parameters are distinguished through the SWOT analysis.

Strengths and weaknesses need to be analyzed in the light of the anticipated opportunities and threats from the business environment. In addition, the concept of competitive advantage points to the importance of evaluating the position relative to the competitors. The first step in this analysis is to take stock of strengths and weaknesses, and then opportunities and threats (table 3).

The purpose of the SWOT analysis is to highlight internal strengths and weaknesses, as well as the main opportunities and threats from the environment. This analysis identifies key aspects of the capabilities of RSR jsc. Doboj to use its own strengths and highlight weaknesses in responding to changes in the business environment.

The results of this analysis help to formulate a strategy for meeting the needs of clients, primarily strategically oriented transport users.

4. CONCLUSION

The structure of revenues in freight traffic generally consists of:

- Revenues from strategically oriented transport users;
- Revenues from other transport users;
- Transit revenues.

In commercial terms - the tariff policy of railways must create an environment for attracting new users, as well as permanently ensure an increased volume of transport from year to year, thus creating the conditions for further development of freight transport activities.

Should the tariff and commercial conditions be changed, the users of transport would try to redirect the goods that were transported by road until now to the railways.

In the coming period, the railways must improve at all levels, that is, at the level of quality of transport services, in order to obtain new quantities of goods from strategically oriented transport users. .

The railways as a carrier in the following period must change the method it operates with transport users in such a way that the railways as a carrier attracts the user and the goods and not vice versa, that the user offers the goods for transport to the railways.

It is necessary to improve cooperation with the carriers in the region, especially in the segment of determination of the price of transportation on the entire route, i.e., that the transport user may obtain information about the price of transport in one spot, and not wait to receive the information for several days. With a view to overcoming this problem, the railways in the region should come to an agreement about the joint participation in the freight transport market as soon as possible.

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COMPETITION FOR THE MARKET ON RAILWAYS – CHALLENGES OF INTRODUCING COMPETITIVE TENDERING FOR PUBLIC SERVICE CONTRACTS

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Abstract – *The next decade will bring numerous changes and challenges to the railway sector because of the scheduled last phase of liberalisation of the railway market for passenger transport in the EU. At the end of 2023, an amended regulation on the public service obligation (PSO) of the EU's fourth railway package enters into force, prescribing new rules for awarding contracts. Until now, EU countries have been able to decide on how to award the contract, and the tender procedure was optional. Competition of railway undertakings for the PSO contract is now becoming the rule. In contrast, the direct award of contracts is reserved only for specific situations and now with more strictly defined conditions. The obligation to award PSO contracts for passengers based on the tender procedure opens numerous challenges, especially for networks with a relatively small traffic volume, such as Serbia. In addition to presenting the changes brought by the new regulation, the paper discusses previous experiences and achievements in awarding PSO contracts in Europe and potential challenges for Serbia and other countries with scarce expertise and resources in the implementation of the PSO tendering procedures.*

Keywords – Passenger rail transport; Contract procurement; Institutional capacity; Procedure design.

1. INTRODUCTION

Gradual liberalisation of the railway market in Europe has placed the railway sector in a transition period that has lasted for twenty years. The disappearance of the old, the emergence of new stakeholders and state institutions, and the formation of new relations to provide end-users with an attractive and green alternative transport service for less cost, step by step, led to the opening of the rail passenger transport market to competition. Of course, the European Commission started liberalising market segments according to the reverse order of their transport volume. International passenger transport, with a share of 6% passenger kilometres (pkm) in 2019 [1], was liberalised in 2009 by applying Regulation 2007/1370/EC. Ten years later, the domestic and commercial passenger transport market by conventional and high-speed trains was liberalised, accounting for 34% of the total number of pkm in the EU. Finally, the liberalisation of the national passenger transport market, which has a dominant share of the railway market in the EU with 66% pkm, is scheduled for 2023.

Entry into this, the last phase of liberalisation, is planned with a different approach than the first two segments. Given that there is no commercial profitability for the most significant volume of passenger rail transport, the state is forced to finance it from public revenues.

Therefore, for the last segment of the market, transportation services are carried out under the Contract on Public service obligation (PSO), where the Competent authority (CA) representing the government orders the transportation service, i.e. chooses a railway undertaker (RU) that would perform this transport under defined conditions. During the contract, one RU carries out transport on one part of the network without competition. He receives a certain compensation for these services that should cover the difference between realised revenues and costs while achieving a reasonable profit.

The gravity on which the liberalisation of this market segment is based in the last round is how these services are procured. Regulation 2007/1370, which has been in force since 2009, introduced the possibility of organising public procurement of these services through competitive tendering and put it equal with the

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current practice of direct award. Of course, the emphasis during the implementation of Regulation 2007/1370 was the introduction of a form of Contract between the CA and an RU that has universal provisions and rules (period of validity, rights and obligations of the participants, types of contracts, performance measurement, etc.) as well as a standard formula for calculating the amount of the compensation. The new Regulation 2016/2338/EU goes one step further and narrows the possibility for direct awarding of the PSO contract by setting the bar higher for applying this mechanism, thus opening up space for the almost inevitable application of competitive tendering. This means that in the transitional period between 2009 and 2023, CAs could try out experimenting with a new mechanism in practice.

Also, the directive from the fourth package 2016/2370/EU, which amended Directive 2012/34/EU, made it possible for RU in passenger transport to freely provide services in any EU member state, not only in the home country – which completely has opened market for passenger rail transport within the Single European Railway Area.

These significant changes expected in the near future impose a fundamental question concerning the market's attractiveness. Will this market become functional, and will it bring the end users and governments the desired effects? In Serbia, the concept of PSO contracts was introduced in 2016, when the ministry in charge of transport concluded the same with the national railway carrier JSC Srbija Voz. As this contract was only valid for one year, a new one has concluded already in 2017, for a period of validity of 5 years [2]. Given that this contract expires in 2022, and a new one is expected to be concluded in the next one, it is a good moment to consider the way and effects of its award. The paper discusses the current and future method of awarding contracts for PSO in the Republic of Serbia as a candidate for full membership in the EU and the challenges that RUs and state or regional authorities can expect.

2. THE CURRENT PROCESS OF THE AWARD AND IMPLEMENTATION OF PSO CONTRACTS IN SERBIA

Both previous contracts in the Republic of Serbia were awarded through a direct award, and only one national RU exists on the rail passenger transport market.

The procedure for the direct award of the PSO contract implies that the CA (at the level of the state, region or city) initiates internal negotiations with a RU that technically meets the conditions for providing the intended scope of the service. It is usually a state-owned RU and a monopolist in this market segment (incumbent). During the negotiations, both parties gradually agree on the conditions regarding lines, frequencies, rolling stock types, and the compensation amount. It is usual for the contract to be concluded for a period between 5 and 10 years, although in EU member states, it is not uncommon for the contract to last up to 15 years. Figure 1 shows the procedure of direct contract award (how it looks in practice in Serbia), where the white colour indicates the activity of the CA, the grey is the activity of the RU, and the joint activity is hatched.

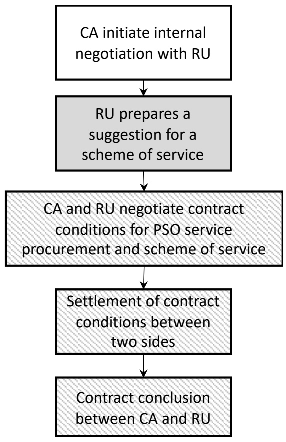

Fig.1. Direct award following negotiation procedure in practice

The negotiations that take place between CA and RU involve defining the provisions of the contract concerning the type and duration of the PSO contract, the volume of traffic that the PSO contract should cover, the list of RU's costs that the PSO contract should cover, key indicators for measuring the RU's performance, quality standards of service provision, reporting and inspection, amount of compensation, reasonable profit and payment conditions. The CA usually adopts the service scheme proposal prepared by the RU without significant changes. After the conclusion of the contract, the practice is that CA and RU conclude an annexe to the PSO contract every year, which defines the services themselves for that timetable, the cost of providing the services, as well as the total amount of compensation paid by CA to RU for the services provided.

During the contract's implementation, the RUs’ performances are monitored. Its effectiveness and service quality are observed using the CA's mechanisms: direct (inspection) and indirect (through a set of established key performance indicators). In addition, passengers can file complaints about the provided service or objections to the timetable quality with the regulatory body, which also exists as a tool for benchmarking RU’s performance. Through these contractually managed mechanisms for PSO, penalties and rewards are initiated for the RU. Based on the Report on the determined obligations of public transport of passengers in railway traffic, published once a year by the Ministry responsible for transportation since 2018 [3] and the publicly available business plans of JSC Srbija Voz [4], the following conclusions can be drawn about the PSO contract management process in Serbia:

- Share of transport services JSC Srbija Voz covered by the PSO contract in the total scope of services is gradually increasing, while the total number of services is decreasing, which indicates the optimisation of its services due to potentially insufficient funding;
- Service quality standards previously agreed upon are not formulated in a way to stimulate the carrier to raise the level of services provided [2];
- The contract does not envisage any penalties;
- The supervising is relatively modest, without gaining direct insight into the actual quality of transportation, especially during the provision of the service itself;
- The amount of compensation is insufficient to cover the cost of provided services. It does not represent an adequate incentive for the RU to develop new services. Along with cost inefficiency, the consequence is the constant generation and accumulation of losses.

From the above, it can be concluded that contract management mechanisms provide almost no effects in practice, which entails further stagnation of passenger rail transport.

3. PROCEDURE OF COMPETITIVE TENDERING FOR PSO CONTRACT AWARD

The introduction of competitive tendering aims to reduce further the cost of procuring these services for the CA and the government. By increasing the transparency of the entire public procurement process through the organisation of tenders, the national RU (the incumbent) is no longer guaranteed to be the only provider of PSO services on almost the whole network year after year, thus losing its previous privileged status. The idea of enabling public bidding for PSO contracts may offer the possibility of participation for many RUs from the Single European Railway Area, which in theory would pave the way to filtering the most efficient RU and lower compensation for the CA.

Participation in the tender is available to any RU that meets the conditions prescribed in the call for applications. The sequence of steps in the procedure is shown in Figure 2. In the first step, the CA announces the tender, prepares the tender conditions and documentation, and finally publishes the call for a tender. Interested participants (RUs) take over the tender documentation and apply for the tender, proving that the conditions have been met. After the CA confirms they have been met, the RUs submit their bids. In the next step, the CA opens the sealed bids, evaluates them and declares the winner of the tender, followed by the conclusion of the contract.

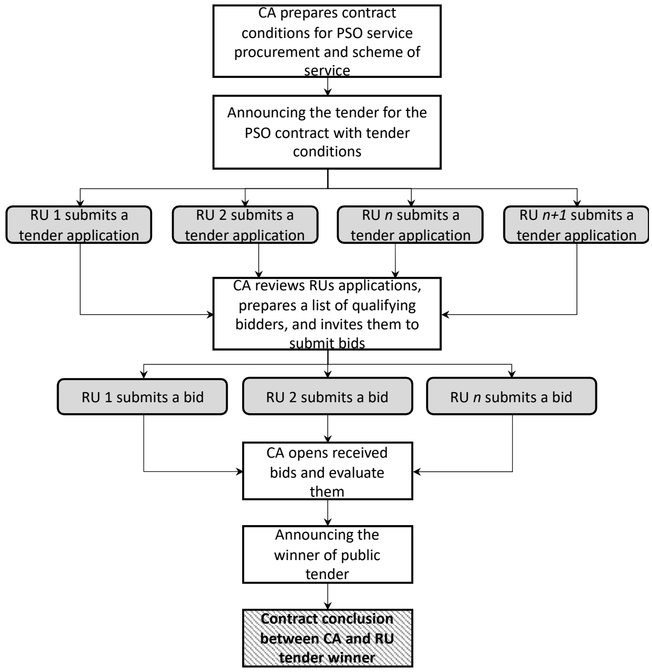

Fig.2. Competitive tendering procedure

The CAs in the EU that have already had the opportunity to organise a tender have most often used a closed reverse auction where RUs submit sealed bids. The RU who bids for the lowest compensation price per unit of operation receive the right to provide the public transport service according to the PSO contract.

4. CHALLENGES OF INTRODUCING COMPETITIVE TENDERING FOR PSO CONTRACT AWARD

Certain EU member states already have experience with competitive tendering for PSO contracts. In practice, these procedures have shown certain drawbacks, and when viewed more broadly, there are several challenges. These challenges relate to the CA and the RU regarding the preparation, organisation, implementation and effects of the competitive tendering. In this section, we will focus only on the most significant ones.

Awarding PSO contracts through competitive tendering contributes to more transparent decision-making when choosing the most efficient RU. However, for two or more competitors to apply for participation at the tender for the PSO contract, they would first have to meet relatively high criteria in terms of technical conditions (acquiring a certain number of rolling stock that meets the technical requirements of using the national infrastructure and hiring a sufficient number of train drivers and other staff). In procuring a single PSO contract for the whole national network, the incumbent would probably be the only one who would meet the conditions, and only he would be able to participate in the tender. To create fair conditions, the CA could split a single PSO contract into several. Each of them would contain the procurement of transport services on a couple of lines. In this way, it would be easier for interested RUs to hire a smaller number of rolling stock and staff ready to provide the service. The second way implies that the incumbent's rolling stock will be taken over by the CA, which would rent them to the winner of the tender under the conditions of the PSO contract [5]. A combination of the first and second solutions is also possible. In this case, a reverse closed auction should be avoided due to the high probability of organising a cartel among RUs.

The attractiveness of the competitive tendering is closely related to the regular funding prescribed by the contract. Since there is no direct connection between a specific source of income in the budget and the financing of PSO services, when planning the budget, the problem of allocation of funds arises due to the multitude of interest groups, which further increases uncertainty about the payment of contracted funds [6]. Also, the RU is in a subordinated position compared to the government regarding negotiating power, which does not contribute to improving the functioning of PSO mechanisms.

The next dimension of the problem is related to the tendering process itself. Unlike the previous way of awarding, where thanks to this asymmetric relationship between the CA and RU, the PSO contract was awarded directly in a relatively short time, now the process requires a lot more time and engagement, especially from the CA. Based on the market study and in cooperation with passenger associations, the CA would have to prepare the plan and specification of the transport services that must be ordered through the tender, then define the bidding conditions and prepare the tender documentation. After the tender, CA is to organise funding, supervision and control of the execution of PSO services. Insufficient capacities of the CAs for the successful performance of these duties, especially in the countries of Eastern Europe, have led to tenders ending unsuccessfully, further jeopardising the functioning of these public services [7].

And finally, in the era of the energy crisis and the fight against climate change, when public transport needs to compete with individual vehicles on fossil fuels, organising competitive tendering, exclusively for rail transport, is too narrow a view of the problem. Only in cooperation with bus transport, their integration in the organisational (spatial coordination of CA in the different modes of transport), operational (synchronisation of timetables, integration of information and tariff systems) and physical dimension (mapping and construction of points of interchange), which is what the concept of *Mobility as a Service* (MaaS) implies, public transport can attract a higher share of passengers. In this regard, it is necessary to have an integrated call for tenders for public bus and rail transport and their optimisation (replacing railway lines with buses, increasing the frequency of trains where railways have shorter transport times, feeder lines, etc.).

5. CONCLUSION

Given that Serbia is a candidate for full EU membership and therefore obliged to harmonise with EU legislation, it is expected to fully harmonise with the provisions of the fourth package of railway regulations. Given the prescribed criteria for the possibility of an exception from the mandatory tender procedure, Serbia will be obliged to award the PSO contract exclusively through a tender.

With the introduction of competitive tendering on the PSO contracts, in addition to the previous activities related to contract management, the preparation of tender documents and the organisation of tenders will be added to the competent bodies. Since in Serbia, the Ministry responsible for transport performs the role of the competent authority, in the process of harmonising with the fourth package, the government should start developing the institutional capacity responsible for awarding PSO contracts as soon as possible. In addition, the importance of more efficient management of PSO contracts and their awarding in Europe has gained additional significance in recent and forthcoming years, especially in the context of the energy crisis and climate change.

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RESTRUCTURING MODEL OF REPUBLIKA SRPSKA RAILWAYS

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Abstract *– Republika Srpska has identified restructuring of the railway sector among top priorities to improve public finance and ensure the provision of high-quality rail services. Modernization of the railway sector was envisaged as the reform of the company in order to operate public rail transport of passengers and goods in accordance with the EU principles and Directives. The objectives of organizational restructuring are to provide the ŽRS with appropriate mechanisms to support their long-term financial sustainability and to align the organizational structure with the railway framework of EU directives and regulations, while creating a clear vision, direction and independence of the role of infrastructure management and operations. The specific objectives of this component include planning and implementation of a new, more commercially driven organizational structure of ŽRS, consisting of corporate core plus two independently managed and separately accounted business divisions, one for infrastructure management and one for transport operations. Within the operations, the accounts will be kept for freight and passenger traffic.*

Keywords – Restructuring of the railway sector, organizational structure of ŽRS, financing of railway services.

1. INTRODUCTION

Restructuring of a company means any change in the structure of capital, business or ownership which goes beyond the limits of the ordinary or daily course of company business [1].

The fundamental goal of company restructuring is to create more value for company owners [2].

"Republika Srpska Railways" (Serbian: *Željeznice Republike Srpske*) operates as a joint stock company, and the ownership structure consists of the Stock Fund of the Republic of Srpska jsc. Banja Luka 63.92%, The Pension Reserve Fund Of Republic of Srpska jsc. Banja Luka 10%, Republika Srpska Restitution Fund jsc. Banja Luka 5% and small stockholders 21.08%. The macro-organizational structure of the company consists of Department of Operations, Department of Infrastructure and Common Affairs.

2. THE RESTRUCTURING PROCEDURE

Republika Srpska Railways jsc. Doboj is currently in a situation when it is necessary to initiate a comprehensive restructuring, both in terms of ownership and financials, as well as the organization [3]. The restructuring of Republika Srpska Railways aims to perform [4]:

- Ownership,
- Financial,
- Organizational restructuring and
- Investments.

In order for all three aspects of restructuring to be implemented almost simultaneously, the only possible way is to implement it through the financial and operational restructuring procedure, which was made possible with the adoption of the new Law on Bankruptcy at the beginning of 2016 [5].

Thus, it has been made possible to convert the liabilities that the Republika Srpska Railways have to suppliers and creditors into basic capital, which directly improves the liquidity position, and also reduces liabilities for regular and default interest (for loans). This procedure, in particular the debt-to-equity conversion of Republika Srpska Railways, primarily

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refers to liabilities based on international loans to the RS Government based on the principal amount of the debt, regular and default interests [6].

The restructuring procedure under the Law on Bankruptcy includes the following steps [3]:

- The Company's Management, with the possible assistance of external associates, prepares a proposal for the restructuring program.
- The Supervisory Board reaches a decision on the initiation of the restructuring procedure and authorizes the director to submit a proposal for the initiation of the procedure to the court, along with the documentation provided for by the Law on Bankruptcy.
- The director submits the proposal to the Commercial Court in Doboj.
- The Commercial Court Doboj reaches a decision on opening the restructuring procedure and appoints a trustee within 8 days (it can be assumed that the Court will need a slightly longer period to reach a decision due to the lack of court practice).
- The trustee analyzes the claims and liabilities.
- The Court schedules an examination hearing.
- In case of reported claims which are not included in the plan, Republika Srpska Railways must change the data on claims in the plan within eight days.
- The court schedules a hearing where the financial and operational restructuring plan is discussed and voted on - a minimum of 25% of creditors as well as creditors who have at least half of the total reported claims should vote for the adoption of the Plan.
- After the adoption of the restructuring plan, the Supervisory Board convenes a stockholders' meeting.
- The Assembly of Stockholders adopts the decision to increase the basic capital by converting liabilities based on (international) loans into capital.

The implementation of the restructuring procedure of Republika Srpska Railways largely depends on:

- Acceptance to convert debt to equity by the RS Government.
- Regularity of grant payments by the RS Government.
- Support from the World Bank, through lending and providing technical assistance.
- Prior to the formal initiation of the restructuring procedure, it is necessary to:
- Conduct consultations with the president of the District Commercial Court Doboj regarding the operational implementation of the restructuring procedure before the District Commercial Court Doboj as the actual and locally competent court.
- Formalize cooperation with the World Bank through a loan arrangement in order to settle the liabilities towards the employees before the restructuring process, which would reduce the number of creditors and make assumptions for the 25% of creditors to vote for the restructuring plan (the RS Government will have more than 50% of the value of receivables through the loan and tax liabilities) and enable financial stability considering that tax liabilities and expenses for informatization of the Company would be settled.
- Obtain a written approval from the RS Ministry of Finance that they will vote to accept the restructuring procedure. [4]
- The measures within the restructuring procedure are as follows:
- Reduction in number of employees through technological redundancy.
- Accounting separation of infrastructure and operator.
- Creation of profit centers.
- Organizing special department to manage the assets.
- Establishing complementary companies with the partners.
- Conversion of debt under international loans into capital of Republika Srpska Railways.
- Payment of liabilities to the RS Tax Administration immediately (loan from the World Bank) or rescheduling of the liabilities to the RS Tax Administration.
- Settlement of the remaining liabilities to employees.
- Infrastructure investments.
- Modernization of rolling stock for passenger and freight traffic.
- Informatization of the Company.
- Appointment of the implementation unit.
- Activation of non-prospective assets.

Activation of assets through public-private partnerships.

3. OWNERSHIP RESTRUCTURING

The first step in the process of ownership restructuring of Republika Srpska Railways would be the conversion of the total debt based on international loans into the equity of Republika Srpska Railways. The debt conversion for international loans refers to the loans from the EBRD, the EIB, the loan from the Portuguese Government, the loan from the Polish Government and a loan from the Serbian Government [4].

The total contractual loan obligations that the Republika Srpska Railways have to the RS Government based on the repayment of international loans, which includes all associated interests (principal + interest + legal default interest), would be converted into the basic capital of the Railways [3].

This procedure would be carried out following the adoption of the financial and operational restructuring plan by the Assembly of Creditors.

The stages of the procedure [4]:

- The Supervisory Board of Republika Srpska Railways convenes a stockholders' meeting.
- The Assembly of Stockholders of Republika Srpska Railways adopts the decision on the conversion of the debt owed to the RS Government into equity, i.e., the decision on the third issue of stocks by conversion of debt into equity.
- Registration of the third issue of stocks in the Register of the RS Securities Commission, the Central Register of Securities, registration of the increase in the basic capital in the court register.

Following the implementation of the debt-to-equity conversion procedure, the ownership share of the majority stockholder would currently reach over 99%, and thus the prerequisites would be met for the initiation of the transfer of the stocks of the remaining stockholders from the ownership structure to the majority stockholder, the implementation of which would make Republika Srpska Railways a single-member joint stock company.

The procedure for transferring minority stocks to the majority stockholder implies the following activities [3]:

- Assessment of the stock value by an authorized appraiser
- Provision of the guarantee of the Majority stockholder for the purchase of stocks.
- The Supervisory Board of Republika Srpska Railways convenes the Assembly of Stockholders
- The Assembly of Stockholders of Republika Srpska Railways adopts a decision on transfer of the stocks to the purchaser (majority stockholder)
- Registration at the court register
- Registration of the stock transfer at the Central Securities Register

It is necessary for the RS Government to accept the restructuring procedure and to appoint the persons who will be in charge of managing the procedure for the purchase of stock from the minority stockholders. Republika Srpska thus becomes the 100% owner of the stocks of Republika Srpska Railways following the conversion of debt into equity and the payment to the stockholders.

4. FINANCIAL RESTRUCTURING

In addition to ownership restructuring, the Company must also carry out the financial transformation. In the process of financial restructuring, obligations under international loans would be converted into capital.

The liabilities to employees and the liabilities to the RS Tax Administration (for taxes and contributions to salaries) will be settled with funds secured by a loan from the World Bank. Until the loan from the World Bank is secured, it is necessary to suspend the calculation of default interest by the Funds and the Tax Administration in order to prevent blockages, while fulfilling the obligations of the Funds.

Liabilities to other suppliers continue to be repaid according to the previously determined schedule [4].

Following these measures (conversion of liabilities under the international loans into capital, loan borrowing with the World Bank) and by reducing the cost of gross wages, along with the regular monthly payment of the grant by the RS Government, the prerequisites for financially stable operations will be created, which will enable the regular payment to all the creditors.

5. ORGANIZATIONAL RESTRUCTURING

The Management Republika Srpska Railways proposed certain organizational changes, primarily in terms of termination of legal and economic affairs, that is, their unification into Common Affairs, along with the segments of investments, internal control, international relations and information dissemination [3].

The primary goal of this proposal of the Management is to clearly highlight two basic business segments, namely Department of Infrastructure, with responsibilities related to the management and maintenance of railway infrastructure, as well as organization of railway traffic, and the Department of Operations, which is responsible for the transport of goods and passengers, as well as the rolling stock maintenance.

A clear statutory highlighting of these two segments, along with the financial separation, is the basis for any future plan of a more thorough restructuring.

The Management Board in the proposed organizational structure, would consist of the general director and executive directors of the Department of Infrastructure and Department of Operations, with a significant increase in the roles and responsibilities of the executive directors in the segments they manage.

The mentioned organizational changes represent activities which are possible at this moment, as the preparation of activities which should be done in parallel with other stages of restructuring [4].

In order to implement the organizational restructuring process, it is necessary for the Company's Management to adopt a new systematization of jobs and to set clear deadlines for its implementation. During the process, the Management is obliged to harmonize the organization and systematization in accordance with status and technological changes in the Company. The Supervisory Board should determine the method and deadlines for reporting on the effects of the systematization adopted by the Management [3].

To meet the requirements of the European regulations in the field of railways, the Departments of Infrastructure and Operations (freight and passenger traffic) will be separated in terms of accounting, with the possibility of a complete analysis of the business performance of each segment separately.

In this way, a quality basis will be created for making a decision on the factual separation of the Departments of Infrastructure and Operations as separate legal entities.

6. OVERALL LOGISTICS FOR A SUCCESSFUL IMPLEMENTATION OF THE RESTRUCTURING PROCEDURE

For a successful implementation of the restructuring process, the Company's Management should appoint teams to implement each of the activities, primarily in terms of organizational restructuring, and especially in terms of:

- Implementation of the new systematization of jobs,
- Preparations and implementation of the new accounting separation of the infrastructure and the rail operator,
- Establishment of profit centers (the Maintenance of Rail Vehicles, as the first step),
- Activation of the asset management unit.

In addition to the teams responsible for the implementation of the abovementioned activities in the restructuring process, for the purposes of supervising the implementation of the restructuring program, it is necessary to establish a unit for the implementation of the restructuring program.

The unit will be tasked to monitor the implementation of the restructuring program in the part financed by a World Bank loan, i.e., all stages of the program except the ownership restructuring [3].

Before the very procedure, it is necessary to:

- sign the agreement on the loan arrangement which includes loan funds for settling obligations to employees (liabilities according to the lawsuits and severance payments, tax liabilities, informatization of the company) and
- prepare all the necessary documentation for submitting a request for the initiation of the restructuring procedure at the competent court.

7. CONCLUSION

Republika Srpska Railways are not financially sustainable in their current role and form. The plan is to conduct the restructuring in accordance with the Law on Bankruptcy, which regulates the field of financial and operational restructuring. In the restructuring process itself, it is necessary to convert receivables based on international loans into the basic capital of Republika Srpska Railways.

By implementing the ownership, financial and operational restructuring of Republika Srpska Railways, the company will be able to regularly fulfill their obligations to employees, suppliers and creditors and to provide quality services, primarily in freight and passenger traffic at the level of services of similar companies from the region.

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INFLUENCE OF SOCIO-ECONOMIC CIRCUMSTANCES ON THE CONSTRUCTION OF RAILWAYS FROM THE VASAL PRINCIPALITY TO CONTEMPORARY SERBIA

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Abstract - *The construction of the first railway line in Serbia began in the late 19th century with almost half a century delay compared to other countries. The small vassal principality of Turkey, which became independent with the Congress of Berlin, found itself in a difficult economic situation, began the construction of a transport system in conditions unlike any country in the world. In addition to the numerous political problems of that time, in all preparatory activities, as well as during the construction of the Belgrade-Niš railway until its completion, Serbia heroically wrestled with enormous financial difficulties. Despite this, the Belgrade-Niš railroad opens for traffic on September 15, 1884. A little less than a month before that, the first railway station in Belgrade, which lasted until this time, was opened for traffic. In 1889, the economy interfered with the fate of the railway again and since the national export office went bankrupt, the Serbian side used this opportunity to establish the Serbian State Railways (SDŽ), which took over the exploitation of the Niš railway from the French company and the given concession fell into oblivion. Activities related to the construction of railways in Serbia took place in three time phases, from 1881 to 1918, from 1918 to 1940 and the third phase after the Second World War until today. The construction of the Bar Railway and its opening to traffic in 1975 was the largest project of that time in the country. Almost 14 decades after the opening of the railway line Belgrade-Niš, a train with a maximum speed of 200km per hour departs from Belgrade to Novi Sad.*

Keywords –socio-economic circumstances, first railway line, SDŽ, ZJŽ.

1. INTRODUCTION

The 2022, as a year of many railway jubilees and year whose "timetable" saw for the first time a train that runs "200 per hour" from the capital of Serbia to its capital of culture, makes us think of the beginnings of the development of transport and the first trains in the world and in our country. After a century of stagnation in economic development, the 19th century arrived, a century of great commitment to the development of transport, especially the railway, its construction and the development of rolling stock.

The economy was crying out for a "locomotive" that would pull it forward. That is why in 1825 the world was amazed by the first train on the route from Stockton to Darlington, practically a mining railway, which was pulled by a small locomotive, with weak traction, but for that time was still the discovery of the century. The captain of this first train in the world was, in the capacity of train driver, none other than George Stevenson himself. He was the designer of that very steam locomotive, quickly upgraded and ready to pull the train on the route Manchester - Liverpool with a speed of 56 km per hour, which soon became a regular service in England. France, Russia, the USA, Africa, Asia and, almost half a century later, the regions of what was then Serbia, soon joined this great progress and put it into practice.

That extremely strong development of railways at the end the 19th century left behind over 600,000 km of railway tracks, of which 526 km were in the Principality of Serbia.

2. GENERAL CIRCUMSTANCES FOR THE CONSTRUCTION OF THE FIRST RAILWAY LINE IN SERBIA

Although the 19th century was the "century of

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railways" and its development which was supported all over the world by development of science, technology and production forces with the blessing of the socio-economic and political actors of that time. In Serbia, on the other hand, due to its numerous difficulties, the construction of the railway was postponed until the end of that century. Although the construction of the first railway in Serbia started half a century later than in other countries of the time, one cannot say that Serbia closed its eyes to every progress of the railway. On the contrary, there are records that the first plans for the construction of a railway through Serbia were made as far back as 1838 during the reign of Prince Miloš, and that the first proposals and attempts to build railways in Serbia were recorded in 1851 during the reign of Prince Aleksandar Karađorđević.

However, the small vassal principality of the Turkish Empire was not independent in decision-making, so without the blessing of Turkey it was impossible to go beyond the plans that had to be hidden most of the time. But Serbia did not stand still when Turkey started some activities on its own without announcing it. When, for example, it turned out that Turkey, without consulting Serbia and its prince, started some activities to build railways through Serbia, as if it was their own property, Prince Alexander courageously, in the spirit of the Serbian struggle against Turkish unfairness, among other things, expelled from Serbia the English land surveyors, who were hired by Turkey.

At the same time, Austria-Hungary strongly encourages the construction of railroads through Serbia and intensively advocates the iron connection to Belgrade and from Belgrade to Constantinople in a kind of fair play, stressing that it has equal respect for all countries through which the railroad is being built. They simply did not hide the fact that the mentioned corridor was extremely important for the economic flow, declaring that common interests create the best connections among the different territories. Turkey did not support this idea and this attitude of Austria-Hungary because its backwardness and hegemony at that time prevailed over the economic needs of other countries. In particular, they had no intention in any case to give Serbia economic and political independence in the management of future railways. Because of such attitude of Turkey, Austria-Hungary, despite the rush to the east, rationally decides to wait for the development of political events, because, otherwise, it could only achieve its goal through war.

Unlike Austria-Hungary and its distant supremacy, economically weak Serbia enters two exhausting wars within two short years. The first, in 1876, following the Herzegovinian uprising, which fortunately did not last long (eight months) and the second, together with Russia against Turkey in 1877, with the aim of liberating the southern cities, especially Niš, the city which was considered a large craft and economic centre, the so called "southern gate of Serbia". That war lasted six weeks, but, together with the first one, it left Serbia with a debt of 30 million dinars (equal to its annual budget). However, Serbia welcomed the Congress of Berlin determined that the construction of the railroad should not be abandoned at any cost.

3. SOCIO-ECONOMIC CIRCUMSTANCES IN SERBIA DURING THE CONSTRUCTION OF THE FIRST RAILWAY

The small vassal principality of Turkey, which became independent at the Congress of Berlin in 1878, found itself in a difficult economic situation. This situation was further complicated by the fact that Serbia took over the obligations of Turkey towards other countries whose territories today belong to Serbia. Nevertheless, Serbia began construction of a transport system in conditions like no other country in the world. Serbia had no peace due to constant demands of Turkey, behaviour of Austria-Hungary which treated it as its protectorate and did not hide its plans for expansion to the Balkans and the general fear of Russia, which was more a pretence than real. In order to be sure to have the leading role in all activities in Serbia related to the construction of the railway, Austria-Hungary did not hesitate to attribute to Serbia that it already had a secret pact with Russia and that, for example, it had already entrusted the construction of the railway Russian entrepreneur. It was proven that these were only provocations because Russia did not even show interest in this railway corridor.

Serbia makes a rational decision and opts for the concession. The Austro-Hungarian Empire immediately began activities in order for one of its companies to obtain a concession for the construction and exploitation of a railway in Serbia, and already had ready proposals for legal acts for the construction of a railway from Vienna to Constantinople. Serbia, in the barely awaited independence from Turkey, had nothing to wait for and made a rational decision and agreed to a contract with Austria-Hungary on connecting the two networks, which implied the obligation to build the Belgrade-Nis railway within three years. The Agreement between Serbia and Austria-Hungary was concluded in July 1878. After numerous negotiations, on 28 March 1880, the Railway Convention was signed, in accordance with which Serbia committed itself to the construction of the Belgrade-Niš-Vranje railway as well as the construction of a bridge over the Sava. On 22 January 1881, this convention and the Berlin Treaty were confirmed by the General Convention for the Construction of the First Serbian State Railway signed by the Government of Serbia and the association General Union. The Agreement foresees the approval of a loan for the construction of the railway from Belgrade to Vranje in the amount of 71,400,000 dinars. This included the construction works and establishment of a company for the exploitation of the railway, which was entrusted to Mr. Bontoux together with the exploitation of the railway for a period of 25 years.

Work on the construction of the railway began on 21 June 1881, but, unfortunately, it was soon followed by financial problems related to the execution of the contract. The construction of the bridge over the Sava stopped. Serbia was in despair and in January 1882 Belgrade found out about the bankruptcy of the union and the irresponsible behaviour of Mr. Bontoux related to the financial part of the contract. In addition to the initial settlement, the General Union as an intermediary, with a commission of 10 million French francs, owed Serbia about 34 million dinars at the time of liquidation, which was about 10 million dinars more than Serbia's annual budget.

With the help of France and Austria-Hungary, Serbia found a new partner for the construction of the railway, to whom, in accordance with the Protocol to the General Convention for the Construction of the First Serbian Railway, it transferred all rights and obligations. Namely, all rights and obligations determined by the convention in question were transferred from the General Union to the Comptoir national d'escompte. Comptoir national d'escompte formed a company for the construction and exploitation of Serbian state railways and covers the debt of the General Union in the amount of 22,800,000 dinars while 12,800,000 dinars were collected from the bankruptcy estate.

With the mobilization of all forces and thousands of builders, the largest state project ever, was finished.

The departure of the train from Belgrade to Nis on the first railway line in Serbia on 15 September 1884 was the main event of the century for Serbia. Following several days of official celebrations in honour of the newly built railway station, which included military marches and cannon shots fired from Kalemegdan, the sounds of the Serbian national anthem marked the departure of the train.

The contractual obligation to build the railway from Belgrade to Niš, which cost Serbia 90 million dinars with a branch to Vranje, was fulfilled. The event was marked as the beginning of a new era in the development of Serbia. For Europe it meant opening of the road to the east. Despite the fact that the connection to the Constantinople railway was not yet been built, the dream of an "eastern railway connection" began to come true.

A month before the opening of this railway, the first railway station was opened for traffic in Belgrade. I was an extremely elegant building on "Bara Venezia", which was used for railway purposes until recently.

Two days before the train to Niš, the first westbound train left from that station over the river Sava, followed by the appropriate ceremony in honour of the King Milan travelling across the new bridge. This event marked the symbolic establishment of a connection between the west and city of Belgrade.

Finally, the economy and finances once again interfered in the fate of Serbian railways and after the Comptoire national d'escompte suddenly went bankrupt in 1889, the Serbian Government formed the Serbian State Railways (SŽD), which took over the management of the existing railway lines and its railways in general as of 3 June 1889.

4. RAILWAYS IN SERBIA AFTER THE WORLD WARS

After a period of high development until the First World War, after the war begins the period of a new state and new conception of railway development and its adaptation to the economic demands. The period from 1927 to 1935 stands out as time of exceptional commitment to the construction of railroads, which, among other things, was an opportunity to employ a large number of workers and practically save them from starvation that threatened them because of the crisis which affected countries around the world in that century, including Serbia. It should also be emphasized that mainly narrow-gauge railways were built for financial reasons. That period is also a symbolic reminder of the famous Lajkovac railway and the town of Lajkovac, which in the thirties of the last century became one of the most important railway junctions of the 760 mm wide railway. Maybe a character named Mile from the famous song was a mythical figure, but Lajkovac was not a myth. It represented an exceptional railway reality of that time and a connection with the whole world.

During this period railways were regulated by national rules. The Decree on the Organization and Formation of Railways in the Kingdom of Serbs, Croats and Slovenes, established the General Directorate of State Railways 1924. As of 1925, the whole territory of the Kingdom of Serbs, Croats and Slovenes had uniformed regulations, standards and tariffs. The Decree on the Organization of the Ministry of Transport and Traffic Services was adopted in 1927. In 1929 the country changed its name to the Kingdom of Yugoslavia and railways were named Yugoslav State Railways.

During the Second World War, and especially during the retreat, the occupier destroyed everything that could be destroyed and Serbia faced unprecedented losses. Many bridges and railways were destroyed – 80% of the passenger rolling stock was destroyed or damaged, and freight rolling stock even more, about 90%. Reconstruction required enormous efforts and sacrifices and wherever possible, standard gauge railways were built. With the closure of the last narrow gauge Požega-Višegrad railway, narrow gauge railways fell into oblivion.

The beginning of the second half of the last century marked major changes in social and economic relations with the introduction of the so-called of socialist self-management, which also affected railways, where workers’ self-management became a reality with the adoption of the Decree on Organization, Business and Management of Yugoslav Railways. The Association of Yugoslav Railways, which included railway companies, was founded with headquarters in Belgrade. With the disintegration of the SFRY, each newly created state established its own railway transport company. In Serbia, it was ŽTP Belgrade, which later grew into "Serbian Railways".

Today in Serbia, instead of one national railway undertaking, we have three market-oriented incumbent railway companies for infrastructure management, freight and passenger transport. As for the construction of railways in the post-war period, the Belgrade-Bar railway was an admirable construction project, so it is no wonder that it was considered as the project that started a new era in the development of railways, the same as the construction of the first railway in Principality of Serbia. The decision to build the railway was made in 1951, the works started in 1952, for some time progressed slowly due to financial reasons, but despite many problems and disagreements, this magnificent railway saw the light of day in 1975. It is the largest and most expensive infrastructure project from the time of the SFRY. The construction of the railway line with hundreds of tunnels and bridges, one of which is the highest railway bridge in Europe, cost 450 million US dollars.

On 19 March 2022, after almost 14 decades since the opening of the first railway line in Serbia, one of the most important state infrastructure projects in the field of railways was finished. As a result, a section of the high-speed railway Belgrade - Novi Sad was placed in service as part of the Belgrade-Budapest railway line with a predicted speed of up to 200 km per hour. The first train on this route named "Soko" (falcon) departed with the highest state leadership on board headed by the president of the state. In the opinion of numerous railway contemporaries, this event marked, for the third time in the history of Serbian railways, a new era of development.

5. CONCLUSION

During the time of the vassal principality of Serbia and long after that, socio-economic circumstances and especially political ones were often difficult for any kind of development of the state and society. In transport, especially in the development and construction of railways, which are extremely demanding, there was a time when it seemed that the problems were insurmountable, although the rulers of all eras, from the middle of the 19th century onwards, were aware of the importance of railways for the economic development of the country. The situation in Serbia was like that as of 1804 and long time after that. Occupied by Turkey and oppressed by Austria-Hungary, Serbia fought for elementary living conditions and, at the same time, dreamt of railways. That time was full of obstacles when it came to the creation of the railway, so what Momčilo Đorganović says in the book "Opanak or Railways" is not far from the truth: "for Serbia, the construction of the railway was equal to the miracle of the Egyptian pyramids".

However, there was something completely atypical in that historical process of building railroads in the then small principality of Serbia and even later. Namely, despite the bad socio-economic conditions, the Balkan and world wars, construction of railways continued and it seems that no other economic branch in those times had such tireless and persistent builders as the railway builders. The cult of railway workers in Serbia has lasted for many years.

Today, railways are certainly the backbone of society, often referred to as a state within a state. Therefore, even though this term is now only symbolic, there is no doubt that the influence of railway transport on the economic development of Serbia is huge and that the railway remains an extremely important factor in the geostrategic, political, commercial and military sense. Plans and decisions of state authorities confirm the above. Realization of the high-speed rail construction project from Belgrade to Budapest as an integral part of the "new silk road" represents a development opportunity for Serbia to be included in all relevant international flows and to use its geostrategic importance in the right way.

The expectation remains that the first railway in Serbia, after almost a century and a half of existence, will shine with modern splendour and illuminate the road from Belgrade to Niš at the same speed as "Soko" does to the north.

Finally, there is still hope that, after the closure of the main railway station, its successor, the "Prokop", will soon become a station worthy of modern times for the benefit of passengers travelling through Serbia via its capital city of Belgrade.

Let the fact that "Bara Venezia", i.e., the place where the first railway station in Belgrade was built, was filled with earth from today's Prokop, be a small prediction that the beauty of Sava Square will be worthily resurrected on a symbolic part of its roots.

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The Graduates and the Future of Railway

ANALYSIS OF IMPACT THE PRESSURE ON THE RAIL VEHICLES AND PASSENGER DURING MOVEMENT

Student: Angelina SAVIĆ[1]
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Abstract – *The aim of this master's thesis is to provide a broader picture that refers to the impact of a sudden change in pressure during the movement of a rail vehicle on passengers, formwork and rail vehicle devices. The highest values of aerodynamic loads of the rail vehicle are achieved when entering and passing through the tunnel. When a train passes through a tunnel, pressure waves propagate along the tunnel at approximately the speed of sound. These pressure waves can penetrate inside the train if the vehicle is not adequately sealed and can cause discomfort to passengers on the train. To avoid negative effects, it is necessary to prevent a sudden change in pressure in the passenger compartment. Active protection means a closed circuit of the air conditioner where the ventilation is constantly on. On the other side, passive protection means closing the air conditioning system during the formation of shock waves, until a sudden change in pressure from the outside is overcome. With this closure, there is 100% air circulation inside the cabin, meaning there is no intake of fresh air. However, there is a problem with the accumulation of carbon dioxide in the cabin of the rail vehicle, over a long period of time overcoming the increase in pressure. The master's thesis deals with the occurrence and spread of pressure surges, the impact of pressure surges on the formwork of a rail vehicle and on a person. The results of the analysis show that the greatest influence on the pressure wave are cross-sections of the tunnel and the train, as well as the geometry of the tunnel portal and the vehicle speed itself. Based on the obtained results, it is possible to reduce the pressure by changing the geometry of the tunnel portal, as well as by increasing the cross-section of the tunnel, and by reducing the cross-section of the vehicle. Considering the respect of the dimensions of the vehicle, the first two options are resorted to. It is also possible to reduce the speed of the vehicle when entering the tunnel in order to reduce the pressure on the vehicle itself.*

Keywords - Pressure waves, Tunnel, Passengers train, Formwork, Tightness.

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TRENDS IN THE RAILWAY TRANSPORT OF GOODS

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Abstract *– Being observed over a longer period, the trends in the transport of goods by rail in different continents, regions, or countries show some form of consistency, although each continent, region, or country is a case for itself. That is a consequence of the development of societies that have common determiners regardless of geographical areas and time differences in their development. Therefore, it is crucial to research the form of those consistencies in the past historical development and the context for observing future development. In this work, we have observed the world, European, and Serbian rail trends in the transport of goods, by researching the available statistics, papers, and databases.*

Keywords - transport of goods, trend, railway, time series.

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DESIGN OF WINDOWS OF ROLLING STOCKS FOR THE PASSENGER TRANSPORT

Student: Milica STJEPANOVIĆ[1]
Mentor: Jovan TANASKOVIĆ[2]

Abstract *– The aim of the master thesis is the research the design and selection of the optimal glass for driver's cabin windows and passenger compartments, as well as their installation in the rail vehicle. The new windows should be designed and implemented in the "Avenio" trams. Choosing a new glass requires it to withstand normal operating loads, including environmental conditions, following EN 15152 and EN 50125-1 standard. In addition to selecting glass, it is necessary to choose the appropriate adhesive for mounting the window in the vehicle structure. In accordance with the Din 6701 standard, an analysis of the type and characteristics of the adhesive was described. The subject is to research and analyze the window load, as well as the thermal and acoustic characteristics of windows. Furthermore, the installation of windows in the vehicle structure and the design of windows for EMU (electric multiple units) were described.*

Keywords – Trams, Windows, Glass, Adhesive, Rail Vehicles.

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RESEARCH OF STRUCTURE OF ACCESS CHARGE FOR THE MINIMUM ACCESS PACKAGE ON EUROPEAN RAILWAYS

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Abstract *– Track Access Charge (TAC) is an important instrument for creating an efficient and competitive railway service in the transport market, and in addition, it greatly influences the increase in the use of railway infrastructure. As such, its structure plays a major role in the efficient operation of infrastructure managers and in increasing the productivity of the railway system. The aim of this investigation is to perform a comparative analysis of structure of TAC for the minimum access package and to find similarities in the thinking of infrastructure managers who have the same or similar characteristics. With the structure of TAC, the infrastructure manager encourages certain behavior of the carrier (formation of trains of certain characteristics, transport at a certain time, etc.) which is in accordance with its goals. Given the diversity of European countries surveyed, a comparative overview by countries is given in order to better understand structure of TAC. The correlation between the presented indicators and the structure of TAC in the most cases is not found or there are very small correlations. It cannot be said with certainty that the cause of the same fee structure is the similarity in the countries. The classification of charges is performed on the basis of the characteristics of the formula, and the two basic criteria are the units of measurement and the relationship between the elements. It can be concluded that charges structures differ greatly in European countries and that despite similar characteristics that some countries have, they still do not have the same structure of TAC and do not solve similar problems in the same way.*

Keywords – track access charge, structure, minimum access package, correlation.

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DEVELOPMENT AND ANALYSIS OF STATIC STRENGTH OF THE PINAFORE FLAPS ON THE LOW-FLOOR TRAM ON THE AVENIO PLATFORM

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Mentor: Jovan TANASKOVIĆ [2]

Abstract *– The aim of the master thesis is weight optimization of the existing construction of the pinafore flaps and production cost reduction as much as possible. This was done by designing a new construction solution and applying of new material, and thus a new way of producing pinafore flaps that are implemented in the construction of low-floor trams of the "Avenio" platform. The "Avenio" platform is a tram model developed by Siemens mobility and it is in use all over the world, so depending on the needs of the customer can be offered different designs. The pinafore flaps are covering the running and the motor bogies, and it is a part of the vehicle body. The existing construction is based on aluminum, while for a new one is used GFRP. The 3D design of the new construction was performed by using CREO Parametric software package. The static strength analyses via the finite element method (FEA) of the existing and new construction were analyzed by using the ANSYS software package. Based on the previous it can be concluded that the new design with a lower mass can withstand normal exploitation load without permanent deformation.*

Keywords – Trams, Pinafore flaps, Bogies, Static strength.

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ANALYSIS OF THE IMPACT OF RAIL TRANSPORT ON THE ENVIRONMENT THROUGH THE ASSESSMENT OF SUSTAINABLE DEVELOPMENT AND EXTERNAL COST

Student: Anica STOJIIĆEVIĆ[1]
Mentor: Sanjin MILINKOVIĆ[2]

Abstract – *Transport has a multiple and very important role for the economy and society of every country. However, even though they have numerous benefits, transportation activities also bring with them certain negative effects. The main negative impacts that transport systems have on the environment are reflected in the negative effect on human health due to emissions of pollutants and noise and the contribution to global warming and climate change. In addition, other adverse effects include land use and the consequences that transport infrastructure has on fragmentation, habitat loss and normal functioning of ecosystems, etc. Although all modes of transport have negative impacts on the environment, they differ significantly between them. The aim of this paper is to present the main impacts of the transport system on the environment through external costs in order to highlight the advantages of the railway in relation to other modes of transport and to point out the justified "title" it holds as one of the most environmentally friendly modes of transport. The advantages of railways depend to a large extent on the conditions and environment in which railways operate, so that despite the possibility of railway transport being sustainable, i.e. eco-friendly and energy efficient, certain negative effects on the environment may still occur in some cases. Therefore, in this paper some of the critical aspects of railways for the environment were discussed and a set of measures and solutions that can be found in application were presented, all with the aim of protecting the environment and mitigating the negative effects of railways which can be increasing, taking into account the planned further development of the railway infrastructure and the increase in the volume of railway traffic in the future.*

Keywords – railway, sustainability, negative impacts, measure.

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GEOMETRY RECONSTRUCTION AND STRENGHT ANALYSIS OF THE DOOR SUPPORT FOR THE METRO TRAIN PLATFORM "INSPIRO"

Student: Milica JOVANOVIC[1]
Mentor: Jovan TANASKOVIC[2]

Abstract *– Metro train platform "Inspiro" presents a base Siemens platform for all future metro systems that the company is going to produce. Platform "Inspiro" should have as many universal mechanical parts and elements as possible. The task of this work was to make a geometry reconstruction of the current construction solution, to ensure cheaper manufacturing of this door support. Different 3D models of the door support, using PTC software package, were constructed that should be manufactured by machining, welding, casting, and forging. To find the optimal solution, it was approached to strength analysis as well as techno-economic analysis. The stress and deformation analysis, and the calculation of the safety factor were performed by ANSYS software package. These analyses show how the door support behaves under the influence of a force of the weight of the door. Also, the aim of these analyses was to find optimal solutions, economically profitable to be able to consider the production and use of the most appropriate construction of door support. In this case, the casting method was chosen as the most profitable way to produce door support for this metro train system "Inspiro".*

Keywords - Metro train system, Construction solutions, Strength analysis, Techno – economic analysis.

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IMPLEMENTATION OF 3D DIMENSIONING THROUGH DESIGN OF SEAT HOLDER ON "AVENIO" TRAM

Student: Ognjen OBRADOVIĆ[1]
Mentor: Jovan TANASKOVIĆ[2]

Abstract *– The development of information technologies with a focus on digitalization allows further development of processes in all fields of mechanical engineering. Computer-aided design modeling is the base for designing Railway vehicles with additional potential to become used in all segments of vehicle lifecycle as a digital twin. These facts provide a guideline for moving to a new way of preparing documentation in 3D form instead of traditional 2D drawings. Because of that, the main subject of master thesis was to investigate the possibilities of preparing and designing documentation in a 3D environment. This thesis was made in cooperation between the Faculty of Mechanical Engineering in Belgrade and the company SIEMENS MOBILITY. All necessary Materials were made in programs that are used in the company working environment. 3D models were made in the program PTC CREO, and the program for presentation of the model with annotations JT2GO. Documentation was made according to ISO standard 16792 based on ASME 14.41 and internal company rules. Model for which documentation was made is a holder for driver seat in tram "Avenio". Finally, research was conducted with several suppliers in Serbia to assess whether there is the possibility of cooperation under these terms, as they are interested in investing and improving in this field and what were their comments. Conclusions were made with results of research and another older research done by ASME institute.*

Keywords – Tram, Design, Digital Factory, Model based annotations, Digital Twin.

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ANALYSIS OF CONSTRUCTION AND THE CONNECTION OF THE TABLE BETWEEN VIS-À-VIS SEATS

Student: Dragana PANIĆ[1]
Mentor: Jovan TANASKOVIĆ[2]

Abstract *– The purpose of this research is to analyze and define requirements for the design of tables located between facing seats in passenger railcars. Tables between vis-à-vis seats are identified as a safety concern during passenger rail accidents because of the risk of serious thoracic and abdominal injury when passengers impact a table during an accident. Also, tables positioned between facing rows of passenger seats can serve to compartmentalize occupants during a collision, which can limit secondary impact velocity and prevent tertiary impacts with other objects or passengers. This paper contains an analysis of existing tables between vis-à-vis seats, including table geometry, table design, materials, flammability, table edge impact response, table attachment methods, crashworthiness testing, and fulfilling these requirements should result in reduced injuries and fatalities due to table impacts during passenger rail collisions. The main goal of this paper was to determine all the parameters directed to the design of this type of table and the way of its installation chosen, with reference to the existing ways of potential improvement and consideration of the standards, regulations, and rules must be applied.*

Keywords – Tables, Vis-à-vis seats, Crashworthiness, Occupant injury.

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RAILCON '22

HIGH SPEED TRAIN

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***Abstract** – The increase in the competitiveness of railway in relation to other types of transport systems in the last sixty years is the result of intensive development of new generations of high-speed trains. High-speed trains are defined as vehicles which running at/above a speed of 250 km/h on a new track or 200 km/h on an existing track. These types of trains provide increased transport speed and, in that manner, shorter travel time, but also requirements for increased reliability, safety and direct application of energy efficiency to the transport system itself. Because of these characteristics, high-speed trains are increasingly used in Europe and the whole world. High-speed trains, which are becoming a major competitor to air transport, due to their speed, price and economy, were discussed in this thesis. In the first part, the adhesive trains that run in many countries in Europe are described. Then the principle of movement of adhesion trains as well as the lines along which they move are shown. The second part of the paper describes the development and way of functioning of magnetic levitation trains, which represent a new type of high-speed trains. In the final part of the work, the technical and operational characteristics of the four-part train marked (KISS EMU 4-part) produced of the Stadler company, which moves along the route Belgrade-Novi Sad, are listed.*

Keywords – Railway, High-speed trains, Adhesion trains, Magnetic levitation trains, Soko high speed train.

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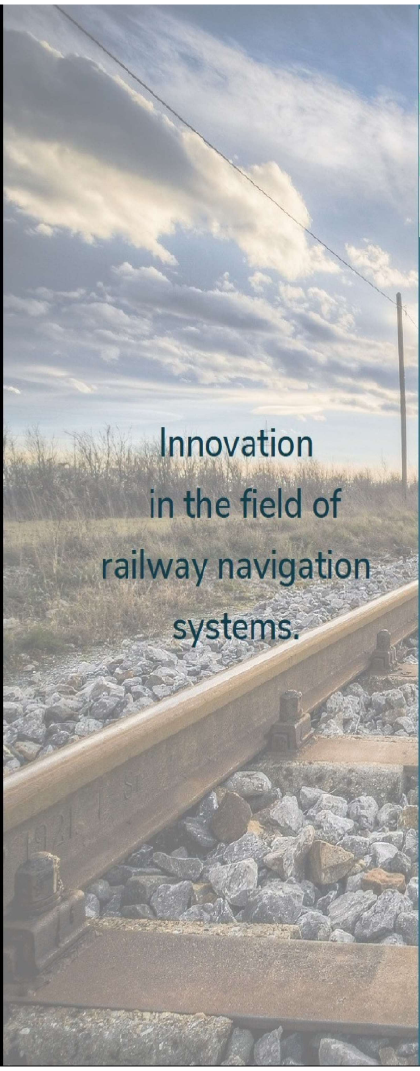

Innovation in the field of railway navigation systems.

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MILE

MULTIFUNCTIONAL INTEROPERABLE LOCOMOTIVE EQUUIPMENT

Universal standalone train control system for safe and coherent transport through various railway networks.

INNOVATION CHALLENGE

Historically, rail safety and maintenance has been under authority of independent national railways with different control command and signaling installations and procedures, which has led to lack of international compatibility. In practice, the problem arises due to technical incompatibility between a train control device and characteristics of the railway infrastructure, meaning that locomotives operating internationally should be equipped with several controlling devices, which is both financially and technically irrational.

These challenges were recognized by the European Parliament and Council by adopting the Directive 2001/16/EC and Directive 2008/57/EC on the interoperability of the rail system within the Community. The suggested solution is the implementation of a new control-command and signaling system - The European Train Control System (ETCS) which is based on the same technical principles of the existing solutions. Given the high cost of implementation and no business case for existing systems replacements, deployment has been slow, so the current spread of new ETCS devices in Europe is on a very low level.

UNI TCS MB SOLUTION

UNIVERSALITY

- Applicable to all railway networks in the class up to 160 km/h.
- Enables transport at any technical environment without additional work on tracks or procurement of any additional equipment.
- Enables running of consecutive trains in the inter-station distance on the principle of "moving block section" without the implementation of train integrity control device.

SELF-SUFFICIENCY

- Covers functionality of all traditionally used mandatory train safety equipment installed in the locomotive (ATP devices, wake-up button, recorder) and operates independently with no need for any external device on rails, which makes it applicable to all railway networks regardless of already installed equipment (balize, loop, etc).

SAFETY IMPROVEMENT

- Detects any kind of forthcoming threatening obstacles on rail tracks as well as devastating tendencies on the railway infrastructure.

EFFECTIVENESS

- The best quality/price ratio with low implementation and maintenance expenses.
- Possible development through implementation of a universal device that would enable communication among all participants in a railway network and further improvement in train management of overall railway performance.

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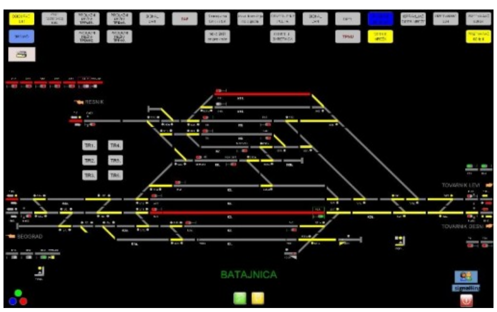
MAIN PRODUCTS:

EMMI - ELECTRONIC MAN MACHINE INTERFACE

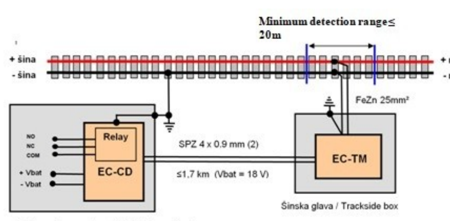


EI - ELECTRONIC INTERLOCKING (SIL4)

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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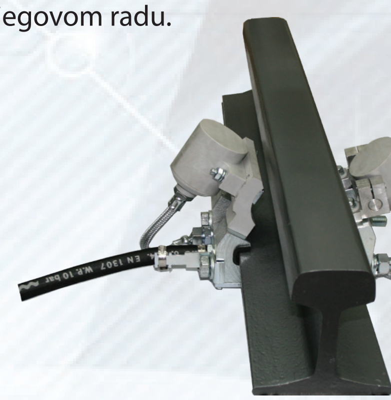
ŽELEZNIČKI PROGRAM INSTITUTA
BEZBEDNOST NA PRUGAMA

Železnički program Instituta "Mihajlo Pupin" čine najnoviji proizvodi vrhunskog kvaliteta i usluge koje nudimo našim klijentima. Čini ga asortiman rešenja i proizvoda koji doprinosi bezbednosti i sigurnosti odvijanja železničkog saobraćaja, a istovremeno železničkim operaterima omogućava da ostvare značajne uštede zbog minimalnih troškova implementacije i održavanja. Najvažniji proizvodi namenjeni železnici su:

Brojač osovina – BROS je uređaj koji se koristi za kontrolu zauzetosti pružnih odseka. Ovaj uređaj može da obezbedi izlaze za 8 pružnih sekcija sa 12 direktno povezanih senzorskih parova.

Brojač osovina je razvijen po najvišim standardima sigurnosti nivoa SIL 4, koji garantuje najveći stepen bezbednosti u njegovom radu.



Univerzalni Tačkasti Detektor (UTD) je uređaj koji se koristi za pouzdanu i preciznu detekciju točka šinskog vozila. UTD je projektovan tako da detektuje točkove šinskih vozila i pri brzinama do 350km/h.

Železnički LED indikatorski signal IND-00 (IND-01 i IND-02) je specijalno napravljen da obezbedi alfanumeričke znakove i simbolične crteže, kao dodatak glavnim železničkim signalima, a može se koristiti i za podzemnu železnicu i u tramvajskom saobraćaju.

Institut "Mihajlo Pupin"
Volgina 15
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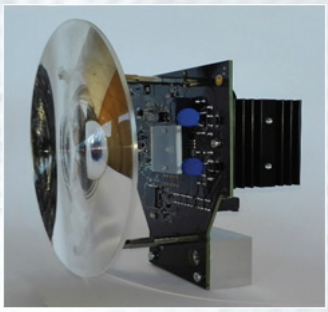
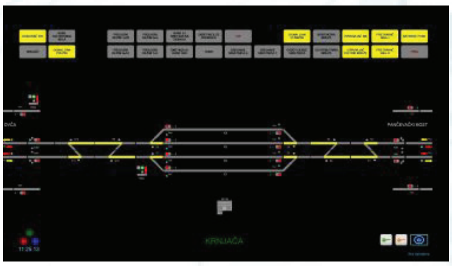
Železnički LED Signal LL-000 je izvor svetlosti koji omogućava kompatibilnost sa interfejsom klasičnih signala i rad u dnevnom, noćnom i trepćućem režimu. Takođe omogućava stalnu kontrolu pomoćnog vlakna na crvenom pojmu.

Zbog složenih radnih uslova relejne postavnice, LL – 000 ima modularan i fleksibilan dizajn koji može da zadovolji širok spektar radnih uslova i primenjiv je na različite tipove sistema staničnih postavnica.





MMI 10 – Sigurnosni železnički komandno – kontrolni uređaj je sigurnosni komandno-kontrolni sistem - HMI (Interfejs čovek-mašina) za upravljanje, nadzor i kontrolu jednog ili više železničkih sigurnosnih uređaja. On pruža grafičku vizuelizaciju kako bi železnički standardi bili u skladu sa korisničkim interfejsom, a da u isto vreme mogu da se koriste sigurno i jednostavno. On se može podešavati i dostupan je na različitim jezicima .

Dostupnost proizvodnih, logističkih i istraživačkih usluga na jednom mestu ima za cilj da podstakne razvoj veština i talenata koji omogućavaju najveću operativnu efikasnost.

Dobro došli u MIND GRUPU

IMW Institut poseduje savremene laboratorije za ispitivanje materijala. Osim tih usluga, Institut se bavi naučno-istraživačkim delatnostima u cilju proučavanja novih materijala kao i promovisanja nauke.

Dobro došli u IMW INSTITUT

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- Određivanje hemijskog sastava metala metodom OES
- Određivanje sadržaja metala iz rastvora metodom ICP/OES

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- Mikrostrukturna analiza

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- Vizuelno ispitivanje
- Ispitivanje tečnim penetrantima
- Ispitivanje magnetnim česticama

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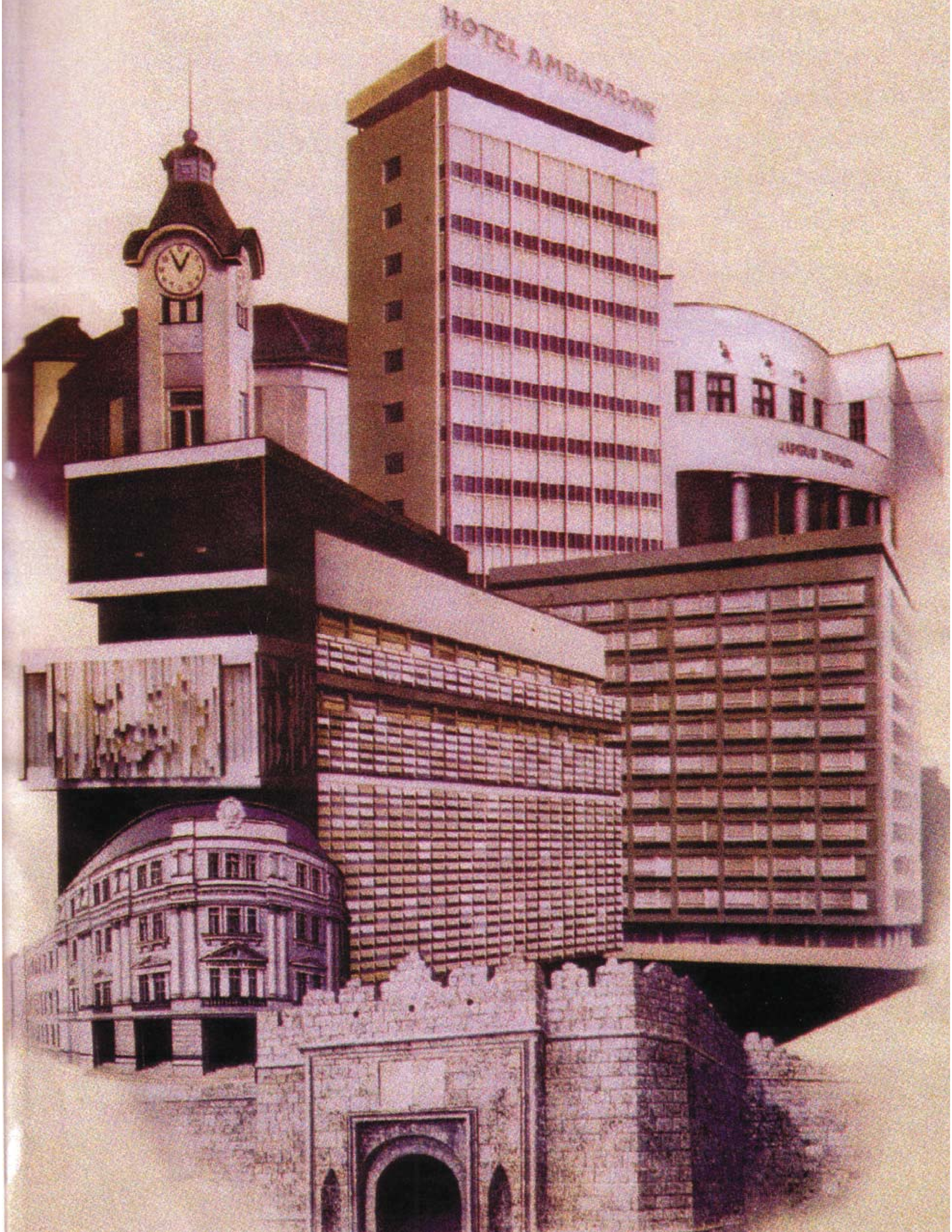
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