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CONTENTS

Plenary session

Rolling stock

Traffic and transport

Infrastructure

Vehicle and infrastructure maintenance

Strategy and policy

Other Railway aspects

The Graduates and the Future of Railway

Plenary Session

ADVANCEMENTS IN THE FIELD OF RAILWAY VEHICLES

Simon IWNICKI[1]

1. INTRODUCTION

This paper presents a number of recent developments in the area of railway vehicle design. These innovative solutions are mainly the products of research projects and have the potential to improve the performance of railway vehicles through, for example, reduced forces on the track or improved ride comfort or resistance to derailment.

2. ACTIVE SUSPENSION

Active suspension as a concept is not new. The components required for an active suspension are now established and widely used in many industries. Partly due to the harsh environment and the conservative nature of the railway active suspension has not been widely adopted although some 'slow active' systems such as air spring secondary suspension or tilting of car bodies in curves are widely used [1].

In the recent 'FORESEE' project [2] a two-axle vehicle was fitted with forced radial steering using slow active pneumatic actuators and full active primary suspension provided by permanent magnet linear motors and associated controllers. This relatively simple active suspension system has been tested and shown to provide good stability with low track forces compared with a conventional two axle vehicle.

Fig. 1. The FORESEE vehicle

3. NOVEL MATERIALS

Railway vehicle running gear is traditionally constructed from cast and fabricated steel components. Although steel provides a high level of reliability and is well understood there are now many 'modern' materials and novel manufacturing methods that offer possible improvements. For example composite materials including fibre reinforced plastics have been used for over 50 years in other transport modes. Carbon fibre reinforced materials offer very high levels of strength to weight and this means that suspension components can be constructed with the required strength in the right places but with much lower mass than steel equivalents.

An example of the use of composite materials in railway vehicle running gear is the 'CaFiBo' Carbon Fibre Bogie project in the UK [3]. In the CaFiBo project a prototype bogie has been constructed from recycled carbon fibre material resulting in a bogie meeting all the performance requirements of the equivalent steel bogie but with less than 50% of its mass. This bogie is currently on test at the University of Huddersfield.

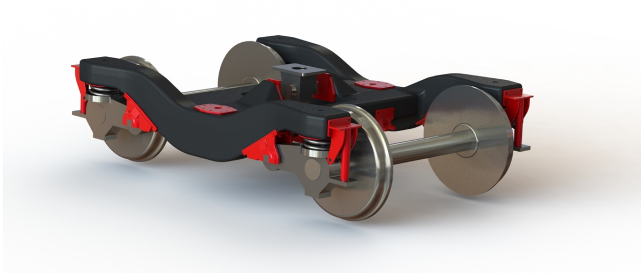

Fig. 2. The CaFiBo carbon fibre bogie

Even greater benefits can be derived from composite materials if the inherent flexibility of the materials can be included in the design of the running gear. This would potentially mean that springs and dampers could be incorporated into the bogie structure.

Other potential material developments include the use of additive manufacturing (previously known as 3D printing). Additive manufacturing allows complex

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shapes to be constructed and, if carefully designed, this means that lightweight components can be constructed with geometries that are precisely tailored to the requirements of the structure and to provide the strength and flexibility required in each direction.

4. BARRIERS

The examples above have shown that innovations in a number of areas have the potential to improve the performance of railway vehicles but there are barriers to their adoption. These include higher initial cost and non-standard failure modes. A key challenge to railway engineers is to be able to build a business case so that manufacturers and investors can adopt the innovations. Tools that will help this are life cycle costing so that higher initial costs can be compensated by lower operation or maintenance costs. Another challenge can be to ensure that benefits in one part of the system are shared across the whole system. For example an improved suspension that results in lower track forces and corresponding reduced track maintenance costs must give benefits to vehicle operators through reduced track access charges.

5. CONCLUSION

There are several innovations that are close to being adopted within the running gear of a railway vehicle. These innovations including active suspension and novel materials have the potential to improve the dynamic performance of the vehicle but there are still significant barriers to be overcome. Further work on ensuring that the benefits can be realised by the vehicle operators is still required.

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[3] Davison K. World's first carbon fibre rail bogie unveiled at 'Unlocking Innovation' rail conference at the University of Huddersfield http://www.elgcf.com/news/worlds-first-carbon-fibre-rail-bogie-unveiled-at-unlocking-innovation-rail-conference-at-the-university-of-huddersfield

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XIX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS RAILCON '20

LIGHTWEIGHT VEHICLES – A NEW PARADIGM IN RAIL FREIGHT

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Petr VOLTR[3]

Abstract - *Lightweight vehicles are an increasingly popular trend in transport technology, for both passengers and freight systems. Therefore, the design of railway vehicles is giving significant attention to lightweighting. This has been mostly driven by considerations for reduced environmental impacts and impact on the infrastructure, higher dynamic performance and improved logistic capabilities. Relevant efforts have been made recently to develop lightweight structural solutions by employing state-of-the-art and emerging materials, manufacturing processes and technologies. Lightweight materials have largely been developed for, and further deployed in aerospace and automotive sectors. However, in the recent past, there has been an increasing uptake in the rail industry for both passengers and freight vehicles. This paper presents the rationale for reducing the mass of rail freight vehicles, to enhance their capacity and capabilities, and, therefore, the overall productivity of the rail freight operation. The background, comprising significant research and engineering work carried out for this specific scope, is briefly summarised. Furthermore, two case studies, which have been recently developed and partially validated within the EU-funded Shift2Rail (S2R) project INNOWAG, are presented, with conclusions and recommendations for potential further work.*

Keywords – Lightweighting; Advanced materials; Rail freight; Lightweight wagon.

1. INTRODUCTION

Lightweighting of vehicles is a hot topic that has been recently addressed through various methodologies by different researches and industries. In this context, railway vehicle manufacturers are focusing nowadays on building lighter vehicles, which are more environmental- and track-friendly.

Significant results have been achieved with respect to vehicle bodies and interiors, particularly in the case of vehicles for passengers. The lightweighting of structural parts is still a critical challenge, due to sensitive issues related to integrity, crashworthiness, fatigue, etc.

The bogie is one of the heaviest assemblies in the structure of a freight rail vehicle. Its lightweighting would contribute considerably to reducing the overall tare weight of the wagon. However, the means of reducing the mass of freight bogies are still limited by the strict requirements imposed to key components such as the wheelset, axleboxes, etc. This affects significantly the outcomes of lightweighting methods and solutions implemented on any type of freight vehicle, due to the high proportion of the bogie weight in the overall vehicle tare weight;

The main method to achieve lightweight construction is to replace materials of high specific weight with lower density materials, without reducing stiffness and durability. Common lightweight materials are, for example, metals such as aluminium, magnesium and high strengthened steels or various types of reinforced composites. Although some of these materials tend to be expensive, their use in railway application is justified with respect to the overall life cycle operational costs. Most lightweighting solutions focused on traditional materials such as steel and aluminium, although the trends and growth of the market show that the use of high-performance composite materials in rail vehicle applications may become an attractive alternative.

The presented research aimed to investigate the possibility of designing lightweight freight vehicles using advanced steel grades and novel structural profiles developed by industry, combined with composite materials, by integrating smart design and

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manufacturing solutions.

Case studies that have been investigated within the recently completed INNOWAG project demonstrate the feasibility of potential approach and subsequent methods for developing lightweight freight vehicles.

2. RATIONALE AND BACKGROUND

Within the EU, there are four main drivers that influence the agenda for lightweighting of railway vehicles. Firstly, it is the need to improve operational agility of freight trains. This requires higher dynamic performance in terms of higher speed, acceleration and braking. The main benefit from this is the potential for freight trains to mixed run with passenger trains, thereby allowing for quicker movement of cargo in a manner comparative to road transport.

The second factor relates to the impact that heavier trains have on the rail infrastructure, as well as negative effects on the train itself, i.e., increased wear of rolling stock components, unintended effect of noise, etc. Overall, heavier trains have higher operational costs due to increased energy and maintenance costs.

Market demand is the third factor. For example, some customers may wish to transport Low Density High Value (LDHV) goods, which requires improved operational agility mentioned above. On the other hand, some customers wish to transport the traditional high-density goods, which requires increased axle load. In both cases, lightweighting solutions would improve operations and reduce operating costs.

The fourth factor is government policies (at both national and regional levels), which identify actions that would promote a particular transport agenda. Example of targets include:

- Increase energy efficiency, including use of renewable energy and electrification;
- Progressing in the reduction of CO2 and pollutants;
- Noise reduction.

Lightweight freight vehicles would help to meet all the three example targets above.

The methods for achieving lightweight vehicle constructions can be classified into three types as listed below [1].

- The first method is to replace materials of high specific weight with lower density materials without reducing stiffness and durability;
- Secondly, structural lightweight construction implies that load-carrying elements and exterior attachments are optimised in their (geometrical) design so as to reduce their weight without any loss in rigidity or functionality;
- The third way of lightweighting constructions is to optimise the production process; for example, in the automotive industry, the reduction of spot welds could reduce the body weight when replaced by new joining techniques such as laser welding or manufacturing processes such as hydroforming.

It is not a trivial matter to conduct lightweight design into railway vehicles, as these are subject to various dynamic loads during their motion on the track. For a new designed railway vehicle, account should be taken of the structural strength of the overall vehicle and its fatigue strength. Furthermore, the dynamic performance of the vehicle should satisfy the requirements in the relevant standards to ensure operating safety.

While reducing the weight of a wagon can be a design target, operators typically consider improving operational efficiency. The increase of the overall transport capacity of freight wagons is a major demand in the actual context aimed to achieve competitiveness and growth for rail freight transport. This objective can be addressed through the following measures:

- *Improvement of wagon specifications:*
  - Optimisation of tare weight to payload ratio (reducing the wagon mass and increasing or maintaining the structural strength);
  - Increase of maximum speed (low impact running gear, efficient braking system, better stability, etc.);
- *Improvement of operational capabilities: Logistics-capable and long-running*
  - Flexible and/or modular design, including features to enable the transport of a large range of commodities and reduce the downtimes and unproductive times;
  - Wagons equipped with interoperable, standard and LCC-oriented components, capable to integrate into different supply chains at reduced operational and maintenance costs.

In this context, both European funded research and rolling stock manufacturing industry have carried out significant work for re-designing the lightweight and flexible freight vehicle of the future, and some of the progresses achieved have been already implemented in commercial products.

The project CAPACITY4RAIL [2] has put forward an argument for a complete wagon redesign. A study conducted under the C4R project indicated that the greatest design opportunity to meet the market needs is lighter wagons with lower tare and higher payload, followed by the installation of detectors for predictive maintenance. This was closely followed by the need for a track friendly running gear to achieve higher axle loads and higher speeds whilst causing less track deterioration and wheel damage.

The SPECTRUM project also developed new technologies and service concepts aimed at improving the rail transport services in ways that would allow rail to enter market segments (LDHV goods) in which it could not compete with road transport using traditional technology or business systems [3]. The greatest design opportunity lay in the design of a lightweight wagon for improved dynamic performance.

Although LDHV goods pose a great opportunity for promotion of a shift from road to rail, it is also key to remember that very heavy cargo cannot be economically transported by road. The SUSTRAIL project indicated that lower axle load flat wagons are increasingly being utilised in Europe and also found that other types of wagons (some flat ones included) tend to carry high tonnage cargo [4, 5]. Subsequently, for these high-density goods (e.g., bulk and aggregates), there is a need to design wagons with higher axle load (25t to 30t). Inevitably, the new wagon solutions would have a tendency to be heavier, thereby increasing undesirable consequences such as impact on the infrastructure and noise. This enables an opportunity for development of innovative lightweighting wagons.

From the wagon productivity perspective, current European wagon fleets are non-flexible. To improve the load factor and ultimately to achieve higher productivity, the development of flexible (e.g., modular) designs of wagons is expected to contribute to the solution of this problem by providing much greater flexibility. This would be an innovative step forward and the rail sector would be required to take radical steps in design and certification if it were to achieve such ambitious goals. However, modular design alone could incorporate a range of cargo loading/discharge options in terms of apertures/door designs and cargo loading/securing systems. The VIWAS project proved that the above desired flexibility can be achieved [6]. Flat wagons can be easily converted to carry not only containers and swap bodies but also general cargo such as timber, building materials, metal profiles and steel. This is possible by using a removable steel platform to be placed on the flat wagons, which, once the transport has been executed, become stackable to facilitate an easy and cost-effective repositioning of the platforms. Likewise, another type of platform can be utilised for flat wagons carrying containers to handle them inside warehouses for accessing them by forklifts. Superstructures are also available for using flat cars in transporting other types of goods. These innovations provide an increased flexibility to the use of wagons.

In addition to relevant research carried out within European-funded projects, a series of significant progresses has been achieved by industry stakeholders. Rolling stock manufacturers, working together with rail undertakings and material suppliers, have developed and tested novel lightweight wagon designs, including bogies, versatile flat wagons and hoppers. The novel solutions are based on the use of lighter materials such as aluminium and/or advanced high strength steel grades (AHSS) for structural parts, combined with optimisation and re-design of key vehicle components and subsystems. Some of these innovations have been already validated and implemented into commercially available products.

3. CASE STUDIES

More recently, the INNOWAG project, funded within the Shift2Rail programme, has investigated different solutions for lightweighting freight vehicles. Potential case studies have been initially identified and general, high-level specifications subsequently defined for selected ones.

Furthermore, selected case studies have been researched for developing relevant lightweight design concepts. The INNOWAG case studies integrate different approaches to lightweight design, and propose design concepts based on modularity, which allow the integration of one or more solutions into the final lightweight concept design of different freight vehicles. Two case studies investigated in the INNOWAG project are presented further:

1. Y25 bogie;
2. U class hopper wagon for cereals.

3.1. Approach and methodology

The lightweighting methodology that was used for developing the INNOWAG lightweight concept designs comprises the following approaches and techniques:

1. Use of advanced materials for different structural parts of the wagons;
2. Optimisation of design using novel profiles and/or re-designing the wagon components and subassemblies using advanced materials;
3. Integration of new technologies with reduced mass that are readily available on the market (e.g., braking system, wheelsets, etc.).

The above techniques have been combined and implemented into novel design concepts for reducing the overall mass of the bogies and wagons in the case studies.

The selection and use of materials for lightweight design is key, therefore, a specific selection methodology has been developed and used, based on:

- The importance/effect on the behaviour and overall properties of the rail vehicle;
- The practicality in using them in the selection methodology.

The material selection methodology employed two categories of criteria:

- Level 1 criteria, including mechanical properties (i.e., specific elasticity modulus, specific tensile strength and fatigue behaviour/strength), material

cost and applicability to different components of the wagon (with respect to manufacturing processes and other specific operational aspects);
- Level 2 criteria, including Life-cycle-cost (LCC), environmental impact and resistance to degrading factors.

The re-design of the lightweight wagon concepts started from the existing traditional designs and comprised a number of iterations necessary for optimising the new designs based on the use of advanced materials. The design work has been supported by specific research and engineering techniques, including modelling and simulation activities:

- Finite Element modelling (FEM) and Analysis (FEA) for validating the structural strength of new designs with respect to static and dynamic loads (in operational conditions);
- Vehicle dynamics modelling and simulation through multi-body simulation (MBS) techniques, for validating the running behaviour of novel designs, as well as the benefits in terms of impacts on the track.

3.2. INNOWAG lightweight wagon concepts

The analysis and assessment of different candidate materials was carried out through the methodology described above, and two families of candidate materials have been selected:

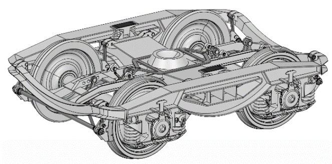
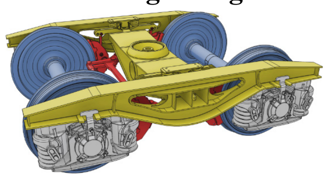
- Advanced steel grades (high strengths steels); and
- Fibre reinforced polymer composites.

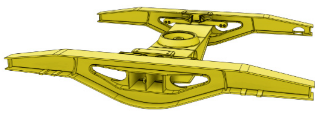
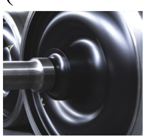
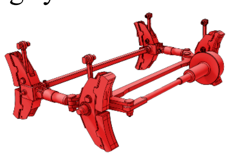
Following on the iterative design process, two relevant lightweight concepts have been developed:

1. Lightweight Y25 bogie;
2. Lightweight cereal hopper wagon – 2 versions:
    - 2.1 Lightweight hopper wagon with non-modified volume/capacity;
    - 2.2 Lightweight hopper wagon with increased volume/capacity.

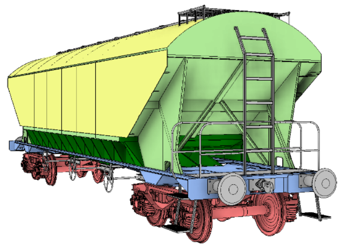
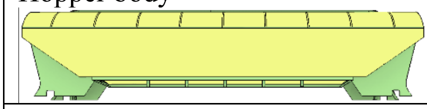
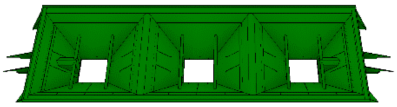
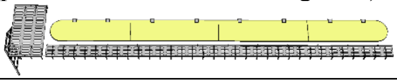
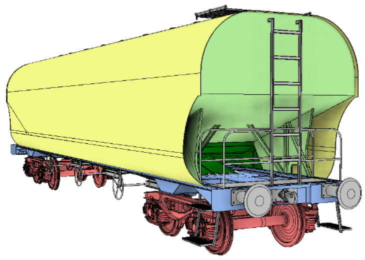
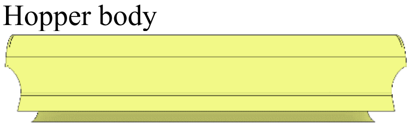
A summary of the lightweight concepts, including details on key subsystems and/or components that have been lightweighted and mass reductions, along with solutions used, are presented in Tab. 1 and Tab. 2.

Tab. 1. Lightweight Y25 bogie concept developed in the INNOWAG project

Reference design	**INNOWAG lightweight design**
	

Component / subassembly	**Masses [kg]**		**Mass reduction**	**Lightweighting solutions**
	Traditional design	**INNOWAG lightweight design**		
Bogie frame 	1112	782	29.68 %	Optimised design. Use of advanced materials (AHSS).
Wheelset (exc. axlebox) 	1121	1030	8.12 %	SURA low stress wheel for freight applications (336kg), by Lucchini AHSS and improved design (with hollow bore) for the axle (358 kg)
Axlebox assembly (per wheelset)	317	317	0.00 %	N/A
Braking system 	514	222	56.81 %	Optimised design and components.
Suspension components (inc. supports)	220	220	0.00 %	N/A
Total Y25 bogie mass [kg]	**4722**	**3918**	**17.03 %**	

Tab. 2. Lightweight cereal hopper wagon concepts developed in the INNOWAG project

Lightweight cereal hopper wagon **Concept 1 (non-modified volume/capacity, 75m^3)**				
Component / subassembly	**Masses [kg]**		**Mass reduction**	**Lightweighting solutions**
	Traditional design	**INNOWAG lightweight design**		
Y25 bogie (INNOWAG concept design)	4722	3918	17.03 %	Lightweight bogies (as described in Tab. 1)
Wagon underframe assembly 	3221	2500	22.38 %	Use of advanced materials (AHSS) Optimised design
Hopper body 	4876	2404	50.70 %	Use of advanced materials (AHSS and composites) Optimised design
Bottom discharge assembly 	1640	1241	24.33 %	Use of advanced materials (AHSS) Optimised design
Roof components (access, protection, covers, loading, etc.) 	1120	794	29.11 %	Use of advanced materials (AHSS and composites) Optimised design
Buffers	506	506	0.00 %	N/A
Coupler assemblies	520	520	0.00 %	N/A
Braking system on wagon (automatic and hand brakes)	1072	420	60.82 %	Optimised design and components.
Steps, handrails and associated access components	134	134	0.00 %	N/A
End platform assembly	168	168	0.00 %	N/A
Total wagon mass	**22701**	**16523**	**27.21%**	
Cereal hopper wagon **Concept 2 (increased volume/capacity, over 85m^3 , +14%)**				
Hopper body 	4876	2949	39.52 %	Use of advanced materials (HSS and composites) Optimised geometry for increasing the volume.
All the other components / subassemblies are similar with those in concept 1 (non-modified volume)				
Total wagon mass	**22701**	**17068**	**24.81 %**	

3.3. Validation of lightweight wagon concepts and technology readiness level achieved

The lightweight concept designs have been partially validated at different technology readiness levels (TRL) through both numerical simulation techniques and testing. Details are presented below for each of the case studies.

- ***Lightweight Y25 bogie concept*** - has been validated at TRL 5-6, through:
  - Bogie frame structural analysis through FEM, in static and dynamic conditions, according to specifications in the European standard EN 13749:2011 [7], referred to by the Technical Specifications for Interoperability (TSI) for freight wagons [8]. In addition, the method specified in guidance ERRI B12/RP17 [9] has been used for determining the load cases in dynamic conditions;
  - Testing of structural strength of prototype bogie frame under exceptional (static) and fatigue loads, as specified in EN 13749:2011, required by the Technical Specifications for Interoperability (TSI).
- ***Lightweight cereal hopper wagon concept*** - has been validated at TRL 3-4, through:
  - Structural analysis of wagon body through FEM, according to standard load cases specified in the European standard EN 12663-2:2010 [10];
  - Non-standard testing of full-scale composite panel solution for application in hopper side walls;
  - Non-standard static testing of samples of hybrid and dissimilar material joints connecting composite panels to steel beams;
  - Impact testing of composite materials for hopper side walls;
  - Abrasion testing of composite samples (for hopper side walls) to determine resistance against abrasive wear, taking into account various options for painting/coating.

In addition, the running behaviour has been validated for both case studies through MBS techniques. The relevant vehicle dynamics parameters have been determined through simulations in conditions designed to replicate the critical operational ones and have been compared to limits specified in standards.

4. CONCLUSIONS

The proposed methodology for lightweighting freight vehicles through the use of advanced materials, design optimisation and use of alternative lightweight technologies for subsystems and components is feasible and can be successfully used for commercial lightweight wagon applications.

The optimisation of major structural parts (through materials, shape and dimensions) has enabled various solutions capable to reduce the overall wagon mass by 20 - 27%.

The analysis of the modified wagon structure partly validates the structural changes and identifies the critical loads, sections and joints. These aspects shall be further analysed and tested for a full validation of the proposed conceptual lightweight design and its implementation into the detailed manufacturing design.

It was found that modelling and numerical analyses have their limitations for specific innovative solutions, including:

- high-strength steel structures - there is less knowledge on fatigue parameters and strength of welds;
- composite materials applications - require advanced modelling to represent the material behaviour accurately;
- numerical modelling - in modelling large complex structures, the representation of joints, interfaces and complex geometry is often simplified to enable the model to be developed and solved in a reasonable time frame.

Therefore, laboratory tests are required to provide further verification of the innovations, particularly in the aspects where problems with numerical solutions have been identified.

The overall results demonstrate that novel steel grades and composite materials can be successfully employed for designing sustainable and feasible lightweight vehicle structures.

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XIX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
RAILCON '20

OBSTACLE DETECTION FOR RAILWAYS: LESSONS LEARNED FROM PROJECT

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Abstract *– In this paper, a novel integrated multi-sensor on-board obstacle detection (OD) system developed within the project "SMART-SMart Automation of Rail Transport", which was funded under the H2020-Shift2Rail-RIA funding scheme, is presented. The SMART OD system combines different vision technologies: thermal camera, night vision sensor (camera augmented with image intensifier), three zoomed RGB cameras, and laser scanner in order to create a sensor fusion system for mid (up to 200 m) and long range (up to 1000 m) autonomous obstacle detection, which is independent of light and weather conditions. All SMART OD sensors were integrated into the sensor housing to enable easy mount and dismount onto/from different test vehicles in different evaluation tests. The integrated OD system prototype was evaluated in dynamic field tests, which were performed on Serbian railway test-site in July 2018 and in May 2019. In the dynamic field tests, the SMART on-board integrated OD system was mounted onto the SERBIA CARGO locomotive 444-017 pulling the freight train with 21 wagons on the Pan European corridor X to Thessaloniki in the length of 120 km. Innovative SMART hardware, supported with novel machine learning-based computer vision software, enabled reliable obstacle detection and fullfiment of functional requirements: frontal obstacle detection, object detection in different environmental and lighting conditions, and long-range obstacle detection. Regarding the latter, the SMART goal was to advance state-of-the-art by long-range object detection. In the first project phase the goal was to go beyond 200 m (mid-range), while in the second project phase the detection distance up to the range between 800 and 1000m (error ±10). Beside the evaluation positive results, this paper also discusses the limitations of SMART OD system and provides lessons learned regarding the additional requirements for autonomous obstacle detection in railways.*

Keywords – Autonomous obstacle detection for railways, Multi-sensor on-board system.

1. INTRODUCTION

Obstacle detection is crucial for the safety of a wide range of applications involving moving elements, ranging from robotic manipulators to manned and unmanned vehi-cles for land, sea, air, and space. As a result of developments in sensor technology and of Artificial Intelligence (AI), in recent years, there has been a rapid expansion in research and development of obstacle detection for road transport. Although railways are the other principal means of transport over land, research and development of obstacle detection in railways has to date lagged behind that for road transport.

Rail is statistically by far the safest mode of land transport in Europe. Nevertheless, there is still scope for improvement of rail safety as each year there is a large number of collisions between trains and objects located on or close to rail tracks [1]. Among various obstacles that can obstruct railway traffic are objects

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such as road vehicles, large fallen objects such as stones and trees, humans and animals (e. g. moose, deer, cow). Such collisions can cause infrastructure breakdown, lead to train and rails needing costly repairs, and cause delays in rail traffic. Collisions with such objects adversely affects train passenger safety, and in most cases kills or severely injures any live object collided with. An image of tragic accident, collision of a train with a passenger bus that resulted in several casualties, which happened in Serbia in December 2018 is given in Fig. 1. Autonomous obstacle detection system, serving as support for driver to timely augment his/her capabilities of viewing the scene in front of the train and to promptly act appropriately , gives significant potential to reduce the quantity of these collisions and to avoid such tragic accidents.

Fig.1. Railway accident near Nis, Serbia, in December 2018. Image source: https://radiobambi.com/vesti/stravican-sudar-voza-i-autobusa-kod-nisa/

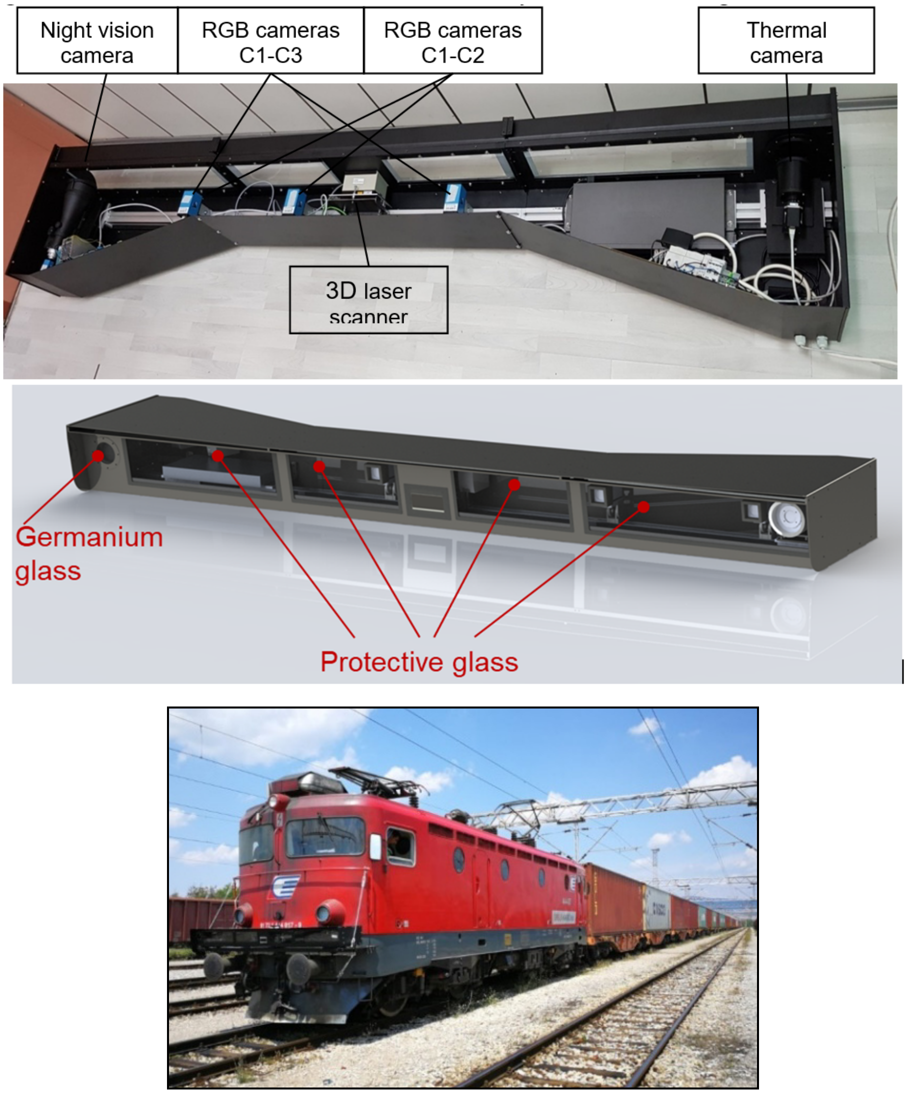

Fig. 2 (top) Final sensors' housing of the integrated SMART ODS demonstrator with the integrated sensors labelled. (middle) CAD model of the closed sensors' housing with protective glass labelled. (bottom) Frontal profile of a SMART test vehicle, Serbia Cargo ŽS series 441, with the ODS demonstrator mounted under the headlights

In contrast to road vehicles, which can change direction to avoid an obstacle, the only way for a train to avoid collision is to come to a complete stop before making contact with an obstacle. This is only possible if the detection distance exceeds the stopping distance of the vehicle. A freight train travelling at 80 km/h has a stopping distance of about 700 m so it is often far too late for the locomotive driver to brake, bring the train to a stop and avoid a collision when an unexpected object is detected on the rail tracks in front of the train [2]. Nevertheless, even if a train needs 1000 m to reach a full stop, the capability to detect certain obstacles at shorter distances can be valuable for prompting the locomotive-driver to decrease the train speed and so to reduce the severity of the collision.

One of the main objectives of Shift2Rail project SMART-SMart Automation of Rail Transport [3] was to develop an on-board sensor-based obstacle detection system able to detect an obstacle ahead of the locomotive at the distance up to 200 m (mid-range) and up to 1000 m (long-range). Different camera types (three zoomed RGB cameras, thermal and night vision cameras) were integrated into the SMART Obstacle Detection (OD) system and were evaluated within the SMART project in order to investigate possibilities of individual sensors and to find a good practical combination of these camera types that took advantage of the benefits of each type. The chosen vision sensors were supported with novel machine learning-based method for object detection and distance estimation from a single camera. In this paper, the results of evaluation of SMART on-board obstacle detection system in operational environment are presented. Also, the lessons learned regarding the additional requirements for autonomous obstacle detection in railways are provided.

2. SMART OD SYSTEM HARDWARE

All SMART OD sensors are integrated into the sensor housing as shown in Fig. 2 (top). The function of the sensor housing is to enable easy mount and dismount onto/from different test vehicles in different evaluation tests. The front panel of the housing is detachable which provides easy access to the sensors. The sections of the front panel are made from the plan parallel tempered glass which provides protection for the camera sensors while maintaining the visibility. The thermal camera is protected by a circular shape Germanium glass which is transparent for infrared radiation (Fig. 2 middle). Additionally to vision sensors, a 3D laser scanner is integreted into the housing. It has already a protective housing so no additional elements for its protection are introduced. At the top of the housing guiding louvers are introduced to guide the air flow from vehicle movement to the protective glass elements. The air flow speed is increased by in a nozzle like system. Such design solution enables the functioning of the system during rain and snow as the high speed air flow sweeps the water/snow particles from the glass protective elements. The sensor housing is designed so to enable different mounting locations. Fig. 2 (bottom) shows the integrated OD system mounted on the frontal profile of the SERBIA CARGO Locomotive 444-017 above the frontal foot support directly below the headlights.

3. SMART OD SOFTWARE

SMART OD software is based on machine learning setup that provides the OD system with a method to estimate the distance from the monocular camera to the object viewed with the camera, which is possible obstacles on the rail tracks ahead of the locomotive. The applied machine learning is based on Multi Hidden-Layer Neural Network, named DisNet, which is used to learn the change in object appearance in an image (in terms of size) due to the change of the object distance with respect to camera viewing the object [4]. Fig. 3 illustrates the system architecture.

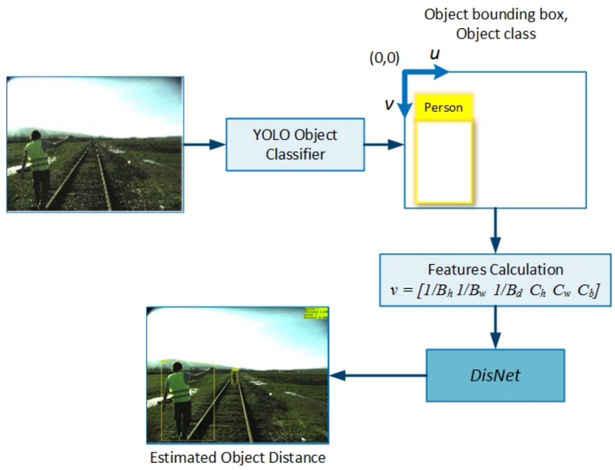

Fig.3. The DisNet -based system used for object distance estimation from a monocular camera

The camera image is the input to the state-of-the-art object classifier YOLO (You Only Look Once) [5] trained with COCO dataset [6]. YOLO is a fast and accurate object detector based on Convolution Neural Network (CNN). Its outputs are bounding boxes of detected objects in the image and labels of the classes of detected objects. The objects bounding boxes resulted from the YOLO object classification are further processed to calculate the features-bounding boxes parameters. Based on the these features, the trained DisNet gives as outputs the estimated distance of the object to the camera coordinate system. In Fig. 3, an example of the estimation of distances of two persons on the rail tracks is shown. The final result is the displayed camera image overlaid with the bounding boxes of the detected obstacles and the estimated distances between the objects and the camera mounted on the locomotive.

DisNet Training - 2000 features vectors **v** dataset was created by calculation of the parameters of manually extracted objects' bounding boxes in RGB images:

B_h=(height of the object bounding box in pixels/image height in pixels);

B_w =(width of the object bounding box in pixels/image width in pixels);

B_d =(diagonal of the object bounding box in pixels/image diagonal in pixels).

Calculated features vectors, **v** have 6 coordinates:

$$\mathbf{v} = [1/B_h \; 1/B_w \; 1/B_d \; C_h \; C_w \; C_b] \tag{1}$$

Besides the inverse of the above bounding boxes parameters, additional features are C_h, C_w *and* C_b that represent average height, width and breadth of the particular object class. For example for the class "person" C_h, C_w and C_b are 175 cm, 55 cm and 30 cm respectively. The images used for extraction of features vectors were captured by RGB camera (one of SMART stereo cameras). In order to achieve sufficient discriminatory information in the dataset, different objects, which could be present in a railway scene as possible obstacles on the rail tracks such as pedestrians and bicycles were recorded. The objects positions were recorded also with a 3D laser scanner simultaneously, which was placed inline with the camera, on the same distance from the imaged objects and on the same elevation as the camera. The 3D laser scanner measurements were considered as objects' ground truth distances in available laser scanner range of 0 – 60 m and were used for training of DisNet as output values

The input dataset was randomly split into a training (80% of the data), validation (10% of the data) and a test set (10% of the data).

4. EVALUATION OF SMART OBSTACLE DETECTION SYSTEM (ODS)

The evaluation of SMART integrated OD system was performed during the multiple dynamic field tests conducted in July 2018 and May 2019. The ODS demonstrator was mounted onto the moving locomotives series 444 owned by SERBIA CARGO („Србија Карго") running with and without attached wagons on two Serbian railway sections: the city of Niš junction round rail track and the Serbian part of the Pan European corridor X to Thessaloniki.

Each dynamic test was performed after obtaining the permits (Fig. 4) for both the use of a locomotive from the vehicle owner SERBIA CARGO and for the mounting of SMART ODS onto test locomotive. The permits were obtained according to the procedural framework for the evaluation dynamic tests defined at the beginning of SMART project [7].

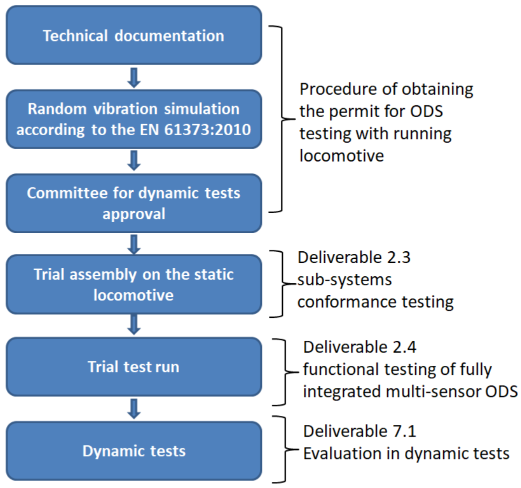

Fig.4. Block-diagram of the steps leading to evaluation of SMART ODS in dynamic field tests (Deliverables refer to deliverables of project SMART [3])

According to adopted procedure, in January 2018, SMART partner University of Niš (UNI) submitted a request for the use of a locomotive series 444 to the owner of the vehicle, SERBIA CARGO. The request was supported with the description of the ODS demonstrator and the detailed description of its mounting/dismounting onto/from the locomotive. In particular, following documents were submitted:

- technical drawings of both the ODS demonstrator sensors' housing, and the mounting construction;
- technical specification of the demonstrator, its components and mounting construction;
- random vibration analysis results for sensor's housing and mounting construction according to the EN 61373:2010 – Rolling stock equipment – Shock and vibration tests for a Category 1 Class B device;
- 3D CAD model of the demonstrator mounted onto the vehicle;
- photos of the manufactured sensors' housing and mounting construction;
- description of the dynamic tests protocols.

Based on the UNI request, the SERBIA CARGO general manager appointed the director of the Train Towing sector as the responsible person for approving the permit after analysing whether all requirements have been met. For this purpose, additionally, a committee of safety experts and engineers from the Niš junction section was formed with the task to review the submitted documentation. As a result of this procedure, the committee requested that the trial OD demonstrator assembly mounting should be performed onto the locomotive series 444 in the Niš junction locomotive depot workshop and that a trial run (functional testing) should be conducted to finally approve a permit for dynamic field tests (evaluation tests).

Fig.5. Trail mounting of the ODS demonstrator onto the locomotive series 444 in the in Niš locomotive depot workshop

The trial OD demonstrator assembly and mounting was successfully completed in March 2018 (Fig. 5) with the members of the SERBIA CARGO committee and with the representatives of the collaborative S2R member project ARCC present at mounting site.

Upon the approval of the trial assembly and mounting by SERBIA CARGO committee, SMART partner UNI submitted a request for the trial test run (dynamic tests) in June 2018. The main component of this request was a description of test protocols and all the actions to be performed during the trial test run. Also, the list of persons involved in the planned dynamic tests was part of the submitted request. The appointed responsible person issued permit for the trial run (functional testing) and approved a test corridor after its requesting from the Infrastructure Manager SERBIA RAILWAY INFRASTRUCTURE.

After the successful functional testing in the trial run, the SERBIA CARGO issued permits for testing in operational conditions (dynamic tests). The main requirement in the permit was that the Serbian railway operating schedule is not disturbed by the SMART OD dynamic tests.

4.1 Dynamic field tests

For the purpose of dynamic field tests, the sensors were integrated into sensors' housing mounted on the front profile of the locomotive (Fig. 2 bottom). The sensors' housing was vibration isolated to prevent transmitting of vibrations from the locomotive onto the cameras as moving vehicle vibration can severely deteriorate quality of acquired images. The vibration isolation system was designed with the rubber-metal springs, as described in [8].

For all dynamic field tests, the SMART OD system was mounted onto the train lo-comotive in the locomotive depot workshop located in Niš junction in Serbia. The locomotives were then running to "Red cross" station, which was the starting point for all dynamic run tests. The following dynamic field tests were performed.

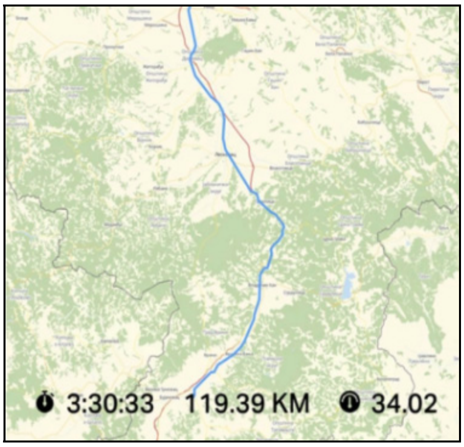

Fig.6. Train route on the Serbian part of the pan European corridor X towards Thessaloniki during the SMART dynamic field tests

- *"Red cross" station - Niš Marshalling Yard – Ristovac on 16.07.2018.*

The test was performed with in service train of the operator Serbia Cargo, Locomotive 444-018, pulling 21 wagons with total mass of 1194 t and total train length of 458 m. The wagons were attached to the locomotive in Niš Marshalling Yard. The test length was 120 km on the Serbian part of the pan European corridor X (Fig.6), the average speed was 34 km/h and the run on the whole length lasted 3.5 h. On the straight rail-tracks sections, between Niš Marshalling Yard and station Grdelica, the maximal speed was 80 km/h. In Grdelica gorge, the speed was limited to 30 km/h due to the highway construction works, which were performed in the gorge at the time of tests. Upon leaving the gorge, the maximal train speed was again 80 km/h. SMART team members mimicked objects (obstacles) on two crossings along the route according to previously adopted test protocols. During the rest of the test, as the train was in real traffic, accidental objects were detected along the route. These objects represented possible obstacles, which could cause an accident, for example a truck crossing the unsecured crossing at station "Momin Kamen" while train was approaching (Fig. 3, first column middle).

- *"Red cross" station – Leskovac – Ristovac on 08.05.2019.*

Fig. 7. Real-world scene: (left) person crossing the rail tracks on unsecured crosing "Momin Kamen" while train is approching. Vehicles parked near the rail tracks; (right) vehicle suddenly changed the status from "parked" to "movingvehicle crossing the rail tracks on unsecured crosing "Momin Kamen" while train is approching

Fig. 8. Real-world scene: persons and an animal (horse) are crossing the rail tracks on unsecured crossing "Medjurovo" (near the Equestrian Club "Nonius") while train is approching; Person on the motorbike is "waiting" on the left side of the rail tracks crossing and a car is parked on the left side of the rail tracks

The test was performed with in service train (Locomotive 444-003) of the operator Serbia Cargo pulling 16 wagons with total mass of 998 t and total train length of 224 m on the same route as the previous dynamic test performed in July 2018. As the highway construction works were finished, the maximal speed on the whole section was 80 km/h. The wagons were attached to the locomotive in station Leskovac. The dynamic test run ended in dusk, with the train arrival to Ristovac station on 19:35, which allowed the dynamic test in different lighting conditions. As in July 2018 tests, SMART team members mimicked objects (obstacles) on several crossings along the route according to previously adopted test protocols. During the rest of the test, as the train was in real traffic, accidental objects were detected along the route.

All dynamic tests were finished successfully, according to the test plans. The mounting and dismounting of the OD system demonstrator was performed under 30 min in all dynamic tests, and there were no disruptions of operations of the Serbia Cargo.

4.2 Evaluation protocols

The overall performance of SMART ODS was evaluated based on the achieved accuracy and reliability on different test cases during dynamic tests. The test cases were defined so to evaluate fulfilling of the functional requirements defined at the beginning of project SMART [7]. The test cases are listed below:

1. *Frontal obstacle detection* – Detection of objects on the rail tracks and near the rail tracks ahead of the locomotive. Targeted potential obstacle was every object found on or near the rail tracks that was not the part of the railway infrastructure.
2. *Object Detection in different environmental and lighting conditions* – Detection of objects on the rail tracks and near the rail tracks ahead of the locomotive in day and night lighting conditions as well as in different weather conditions.

Fig. 9. (left) Object detection and distance estimation in on-board thermal camera image recorded in environmental condition of 38°C; Good detection result in spite of low-contrast image; Ground truth distance for person: 155 m (error 0,025 %); (right) Object detection and distance estimation in night vision camera images recorded in night (poor) lighting conditions. Ground truth distance: 225 m (error 0,41 % and 5,43% respectively)

Fig. 10. Object detection and distance estimation in RGB camera image recorded in winter (snow) environmental conditions; Ground truth distance: 835 m (error 0,97 % and 1,74% respectively)

3. *Long-range obstacle detection* – The SMART goal was to advance state-of-the-art by long-range object detection. In first steps the goal was to go beyond 200 m. In the second phase the detection distance up to the range between 800 and 1000m (error ±10).

4.3 Evaluation results

The evaluation results of performed evaluation tests are illustrated below with real-world images, captured by on-board SMART OD sensors, overlaid with object detection and distance estimation results.

Frontal obstacle detection

1. *Object Detection in different environmental and lighting conditions*

The evaluation dynamic tests were performed in July 2018 and May 2019. In July 2018, the environmental temperature was 38°C, which influenced the thermal camera of low contrast so that developed SMART software had to be developed robust to external conditions influencing the image quality. As both dynamic evaluation tests were permitted to be performed in summer/spring, the weather performance evaluation of ODS in different environmental conditions could not be evaluated in dynamic tests. However, static tests in November 2018 and March 2019 were performed in different environmental conditions and yielded positive results (Results given in Figures 9(right) and 10). Therefore, similar performance of the ODS can be presumed under different operational conditions as well.

1. *Mid (up to 200 m) and Long-range (up to 800 m – 100 m) obstacle detection*

Due to geometry of the rail tracks in dynamic tests, there were no straight rail tracks sections longer than 600 m on which accidental objects could be detected. However, Mid- to Long-range results of about 200 m - 600 m were achieved as illustrated in Figures 14, 15 and 16. Static tests were performed in November 2018 on the straight rail tracks in length of about 1000 m, with the planned (mimicked objects) on the whole length, complementing so dynamic tests (a result shown in Figure13; details given in Deliverable D3.2 and in the publication [Haseeb et al, 2019]). Due to

Fig. 11. (left) Mid-range object detection and distance estimation in on-board RGB camera image; Ground truth distance: 272,75 m (error 10%); (right) Mid-range object detection and distance estimation in on-board RGB camera image; Ground truth distance: 231,97 m (errors 8,2% and 8,24% respectively)

Fig. 12. Mid- to Long-range object detection and distance estimation in on-board RGB camera image; Ground truth distance: for persons (station middle point) 266,69 m (average error 8,32%), for the car 597,87 m (error 0,69%)

the positive results achieved in static field tests, similar performance is expected to be achieved in operational conditions as well.

5. LESSONS LEARNED FROM THE EVALUATION TESTS

As presented in section 4, the evaluation tests showed that SMART OD system meets all functional requirements defined at the beginning of project SMART [7]. However, evaluation tests also revealed the limitations of SMART OD prototype so that additional requirements for an OD in railways are suggested as the outcome of project SMART. These are: classifications of wider range of object classes including “dangerous” objects like fallen trees and controlling of vision sensors (cameras) direction so to achieve human-like performance of changing viewing direction when examining an area ahead of the locomotive for hazardous objects on the rail tracks and near the real tracks.

Namely, control of camera direction in horizontal plane can greatly improve OD capabilities. In order to get initial knowledge on possibilities of controlling the camera direction, at the end of project SMART, experiments were performed with the fixed position zoomed RGB camera with the optical axis co-linear with the train direction (as it is the case in SMART OD system) and with the thermal camera mounted on the gimbal. The thermal camera was mounded on-board on the hand rail and it was integrated onto a gimbal enabling its +- 90° vertical rotation and +-60° rotation in horizontal plane. The distance between the cameras was 1.5 m. The thermal camera was equipped with 100 mm objective in order to detect objects at larger distances.

As it can be seen from recorded images shown in Fig. 13, in curve, the zoomed RGB camera sees only a small portion of the right track (the train track) of about 50 m. Instead of rail tracks, the RGB camera “looks” at the hill, vegetation and house next to the track. Thanks to the online control of thermal camera’s direction, as it can be seen from thermal image (Fig. 13 bottom), the thermal camera “sees” the whole curve area and it can even see behind the curve if there is no object to block direct visibility. Confirmed initial results indicated the need for inclusion of this functionality in an on-board OD system for railways.

Fig.13. Rail tracks curve as seen from the fixed view on-board RGB camera (top), controlled view on-board thermal camera (bottom)

6. CONCLUSION

In this paper, a novel integrated on-board multi-sensor obstacle detection (OD) system, which was developed within Shift2Rail H2020 project SMART, is presented. The hardware and the software of the system are described. The particular focus of this paper is on the results of the evaluation performed through dynamic field tests, which were conducted at the Serbian railways in July 2018 and May 2019. Successful dynamic field tests proved the reliability of using the developed OD system on the running train. Conducted dynamic field tests also indicated the limitations of SMART OD prototype, which resulted in suggestions of additional requirements for an OD system for railways.

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Rolling stock

XIX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS RAILCON '20

SPECIAL FEM SUPERELEMENT IMPACT ON THE TOPOLOGY OPTIMIZATION TIME CONSUMPTION

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Abstract *– Topology optimization is increasingly used in the design phase of rolling stock components. Using this approach the optimal shape of the car body structure as well as rolling stock subsystems such as frames, supports, cantilevers etc. is determined. The task of topology optimization requires a series of iterations to find a solution, which involves a large consumption of time. To determine the optimal shape of individual components / subassemblies, an optimization process is required, which includes the optimized component as well as all or part of the car body structure (environment). In order to minimize the number of finite elements in the model, it was decided to replace the environment with a superelement. The use of a superelement not only affects the time needed to solve an optimization task, but also often, in the case of very extensive optimization problems, allows you to solve the task by eliminating hardware limitations. The article presents the results of topology optimization of the seat cantilever carried out without and with the use of a superelement. The results obtained and the computation time were compared.*

Keywords – optimization, FEM, rolling stock, SIMP method

1. INTRODUCTION

Optimization can be defined as an automatic process, thanks to which the system or component meets the set criterion / criteria while maintaining the specified design assumptions. The optimization task presented in this article as well as numerical analyzes were performed in the Altair HyperWorks (HW) software using the OptiStruct solver.

There are many different optimization algorithms. OptiStruct HW software is based on the gradient algorithm used in the topology optimization method. It is a mathematical technique that produces an optimized shape and material distribution for an optimized component in a given area. OptiStruct solves topology optimization problems using the solid isotropic material with penalization (SIMP) approach, using the finite element method (FEM) [1]. The SIMP method predicts the optimal distribution of material in a given design space for specific load cases, boundary conditions, manufacturing constraints and performance requirements. The material density in the area of a single finite element of the discretized structure ranges from 0 to 1, respectively defining the element as useless or needful, adequately below or above the declared limit value. The limiting value is usually taken as an element density of 0.7. Finite elements with a lower value are considered useless. [2,3,4]. An example of the topology optimization task based on SIMP method is presented in ***Fig. 1***.

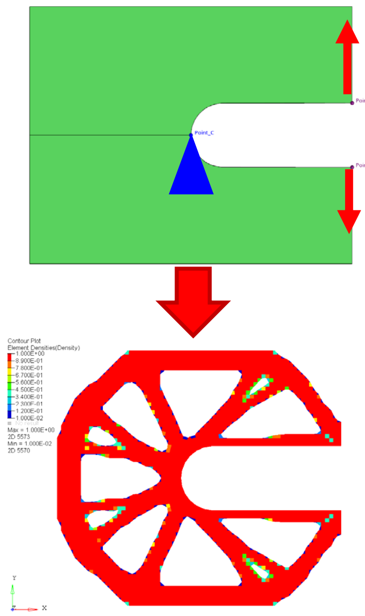

Fig. 1. Example of topology optimization using SIMP method [5]

The task of topology optimization requires a series of iterations to find a solution, which consumes a lot of time. The time of each iteration, and thus the total

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time of the optimization process, is primarily influenced by the complexity of the boundary value problem, which is in turn affected by the number of finite elements in the model. In the construction of rail vehicles, to determine the optimal shape of individual components / subassemblies, it is required to carry out an optimization process that includes the optimized component as well as all or part of the car body structure (as an environment). Taking into account the environment of the component, on the one hand, is necessary to accurately reflect the stiffness of the structure and the method of connecting the optimized subassembly with the rest of the complex structure, and on the other hand, it significantly extends the calculation time. In order to minimize the number of finite elements in the model, it was decided to replace the environment with a superelement [5]. A superelement is a special finite element with specific properties. In the case of this work, it is defined by grouping and processing a set of selected finite elements of the model (environment). The use of a superelement not only affects the time needed to solve the optimization task, but also often, in the case of very extensive optimization problems, allows the task to be solved by eliminating hardware limitations.

2. DESIGN ASSUMPTIONS

The seat cantilever is the component subjected to the optimization task. The location of this component is shown in Fig. 2.

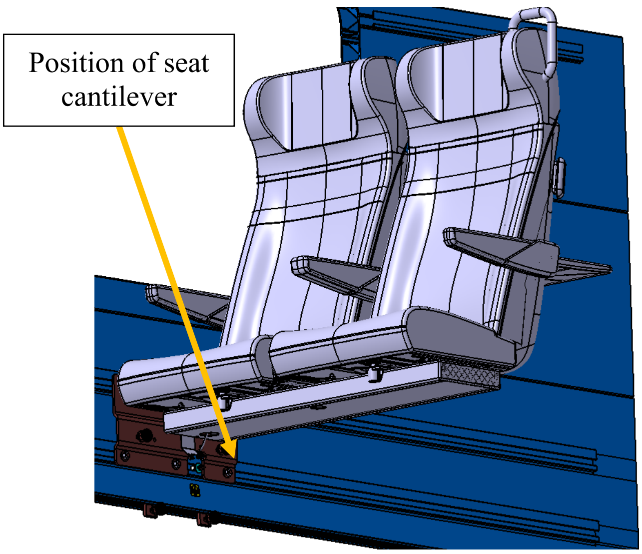

Fig. 2. Seat cantilever position

In order to reflect the stiffness of the system and the method of fixing the cantilever, the numerical model was extended to include a part of the car's supporting structure (Fig. 3). It was assumed that the material of which the bracket will be made is aluminum alloy with properties listed in Tab. 1.

Tab. 1. Material properties of aluminum alloy AW6082-T6

Young modulus [MPa]	Density [g/cm^3]	Poisson's ratio
$7 \cdot 10^4$	2,7	0,3

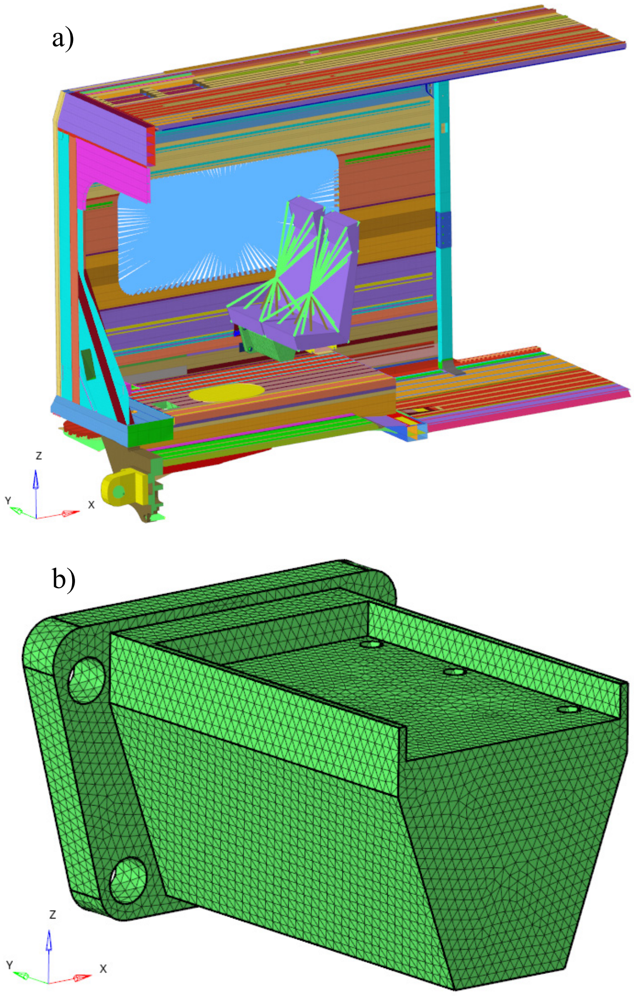

Fig. 3. A discrete geometric model: a) a model taking into account a part of the car structure, b) a model with an introduced superelement replacing the car structure

3. FEM MODEL, BOUNDARY CONDITIONS (BC) OF SUPPORT AND LOADING

The discrete model for the cantilever optimization task was created from shell and solid elements, contains 290,000 elements, respectively 150,000 quad4 elements and 140,000 tetra10 elements and 335,000 nodes, while the cantilever model itself consists of 140,000 tetra10 elements and 198,000 nodes.

The model was supported by taking all degrees of freedom (DoFs) in the plane of intersection (YZ) and by taking degrees of freedom in the XZ plane according to symmetry conditions. In addition, the possibility of displacements along the Z axis at the place of the air spring (secondary suspension between the bogie and the car body structure) as well as along the X axis at the coupling point was taken away.

The cantilever model was loaded with the forces resulting from the weight of two seats (2 x 21 kg) and the assumed weight of two passengers (2 x 70 kg). The safety factor was assumed to be equal to 3, in accordance with the PN 12663 standard. The net force acting on the seat support is 5371 N and was equally distributed over both seats and applied to the center of gravity of each set (seat + passenger). Three load cases were considered:

- force in the + X direction,
- force in the -X direction,
- force in the -Z direction.

The boundary conditions and the applied loads are presented in Fig. 4.

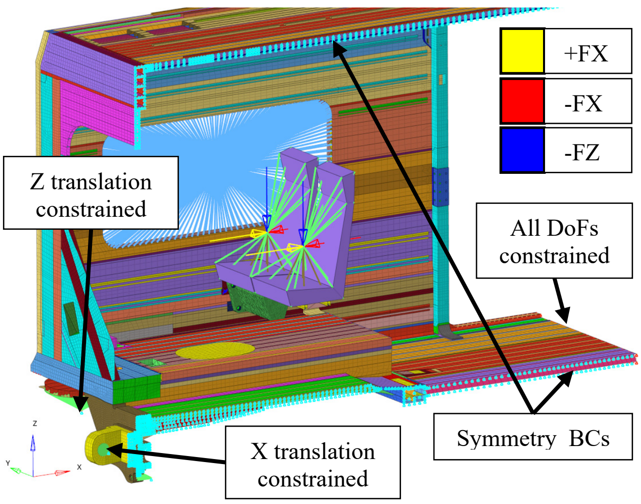

Fig. 4. Boundary conditions of support and load

4. TOPOLOGY OPTIMIZATION

The seat cantilever is the component subjected to the optimization task. The task is to minimize the mass, with the assumed limitation imposed on the maximum reduced stress (Huber-von Mises) occurring in the cantilever. It was assumed that the maximum stresses cannot exceed 70 MPa. The topology optimization of the cantilever was carried out for the numerical model taking into account a part of the car body structure as well as for the case with the added superelement replacing the car body structure.

The superelement in HW software is generated using the static condensation method [2,5]. This method creates constraints at nodes in the plane where the environment meets the optimized subassembly. The first step in the process of preparing a numerical model with the use of a superelement is the analysis of the entire assembly with the optimized component and determination of the displacement field in the contact plane. On the contact surface of the part subject to optimization with the environment as well as on the nodes where boundary conditions were applied, ASET type contraints were created, which are used to transform the obtained displacement field and define the superelement (Fig. 5).

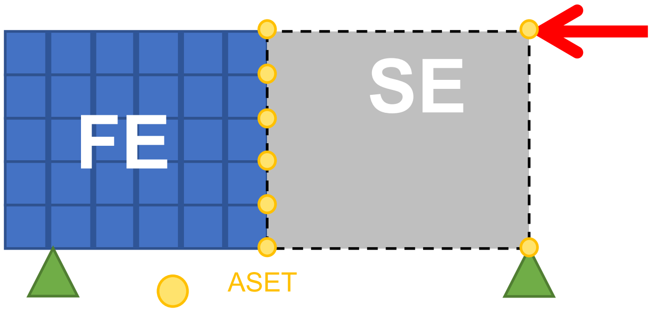

Fig. 5. ASET constraints [5]

The next step was the analysis as a result of which Optistruct generated the result file containing the reduced stiffness matrix of the superelement replacing the environment and reduced model validation, which consists in checking the convergence of results between the full model and the model with the applied superelement. This stages were followed by optimization process. Optinally, at the end of the optimization process it is possible to create a 3D model based on the results. Topology optimization precess with the use of superelement is presented on the graph presented in Fig. 6.

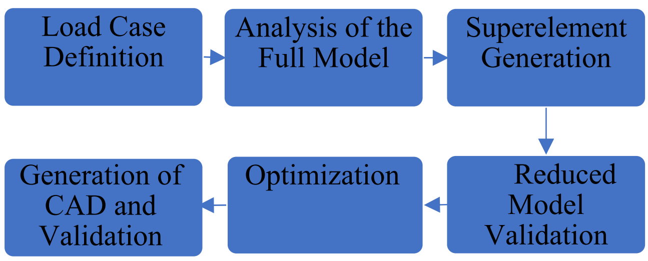

Fig. 6. Computation process

5. RESULTS

Fig. 7 shows a comparison of the optimal shape obtained as a result of the topology optimization of the cantilever for the numerical model taking into account a part of the wagon structure and for the case with the introduced superelement replacing the wagon structure. The results are almost identical for both methods. However, attention should be paid to significant time savings in the case of using a superelement (Tab. 2).

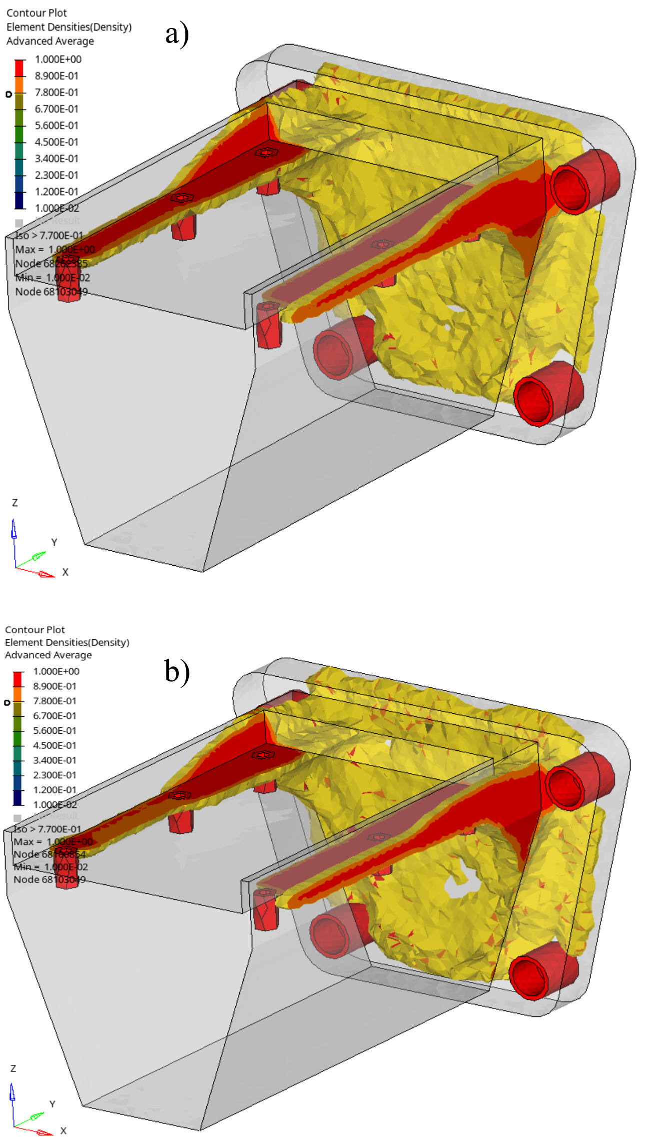

Fig. 7. Topological optimization results: a) topology optimization for a numerical model with a part of the car body structure, b) topology optimization with a superelement replacing the part of the car body structure

Tab. 2. Comparison of calculation time

	Optimization of the numerical model with a part of the car body structure	Optimization of the model with the introduced superelement
Time [h:m:s]	04:57:44	01:31:20
Mass reduction for element densities less than 0.7	83.0%	83.5%

6. CONCLUSIONS

On the basis of the conducted analyzes, it can be seen that the use of a superelement instead of a numerical model of a part of the car body structure does not affect the obtained results (in this case, the weight reduction) and the optimal shape and significantly reduces the computational time.

ACKNOWLEDGEMENT

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XIX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
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NUMERICAL RESEARCH OF IMPACT OF TUBE WALL THICKNESS AND POLYURETHANE FOAM DENSITY ON ABSORPTION CHARACTERISTICS

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Dragan MILKOVIĆ[2]
Vojkan LUČANIN[3]

Abstract *– Implementation of collision energy absorber in bearing structure of the current railway vehicles presents a big engineering challenge. A main challenge is to develop compact absorber suitable for installation in a very limited space at the front beam. Beside to compact dimensions, designer has a task to create absorber with required absorption power and the most acceptable deformation scenario during energy absorption. Previous investigations of the different types of collision energy absorbers have shown that shrinking tube absorber gives the best output parameters. The subject of this paper is numerical research of the impact of tube wall thickness and polyurethane (PU) foam density on energy absorption and specific energy absorption of shrinking tube absorber. Using this type of absorber, energy absorption arises: 1) elastic-plastic deformation of tube wall, 2) friction between absorption elements and 3) compression of PU foam inside the tube. The paper presents numerical simulations performed in ANSYS Workbench software using the quasi-static behavior and a plane axi-symmetric model. Analysis of empty and foam filled tube were done. Validation of developed numerical model was realized by comparison with experimental results obtained via previous quasi-static tests. Results of numerical simulations showed that increase of wall thickness leads to significant increase of mass and deformation resistance, respectively. Greater mass in comparison with purpose and benefit of absorber is absolutely acceptable, but a sharp increase of the deformation resistance may induce uncontrolled distortions of wagon structure before a fully utilization of absorber. On the other side, increase of PU density gives lower increase of deformation resistance in comparison to previous one and negligible increase of mass. Mentioned parameters were carefully analyzed and influence of them on energy absorption and specific energy absorption was discussed. Presented numerical analyses showed that it is possible precisely to set absorption characteristics without performing experimental tests, and to reduce development costs by using validated numerical model.*

Keywords – Railway Vehicles, Numerical Simulations, Energy Absorber, PU Foam

1. INTRODUCTION

Perennial work in field of passive safety of railway vehicles gave a many useful results used for development of different types of collision energy absorbers as well as numerical models that can help in design of absorption elements. Shrinking tube absorber showed the most acceptable absorption characteristics in comparison with other types. Subject of this paper is development of numerical model of shrinking foam filled tube absorber, validation of it and analyses of impact of main parameters. The aim is to form numerical model simplified as much as possible, but which must correct simulate shrinking process of the tube and compression of rigid polyurethane (PU) foam inside the tube. Base for forming of numerical model are previous experimental investigations [1-3]. Results presented in these papers show that is possible to use numerical simulations in design process to get absorption elements which can absorb requested amount of collision kinetic energy. In addition, material model used in these investigations showed as acceptable and gave realistic image of behavior of tube material during deformation process. Properties of rigid PU foam of density 175 kg/m^3 were recorded via test of

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PU foam specimen under axial load. The main parameters for a few different density of PU foam, next to previous one, were taken from experimental results presented in the papers [4-7].

Numerical simulations of axial load of empty and foam filled seamless tubes were performed. Results obtained by these calculations were used for analyses of impact of different parameters on the absorbed energy (AE) and the specific absorbed energy (SAE).

2. NUMERICAL SIMULATIONS

Quasi-static numerical simulations by using ANSYS Workbench software package on the plane axi-symmetric models were realized, Fig. 1.

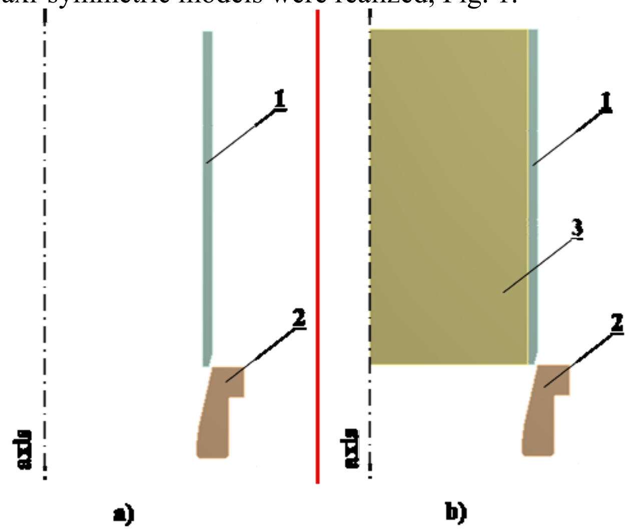

Fig.1. Numerical models: a) empty tube and b) foam filled tube (1-semaless tube, 2-cone bushing and 3-PU foam)

Axial symmetry of absorber configurations, empty tube and foam filled tubes, give possibility for using plane axisymmetric numerical model. This option allows very good simulation of material behavior and way of deformation, and significant decrease of calculation time on the other side.

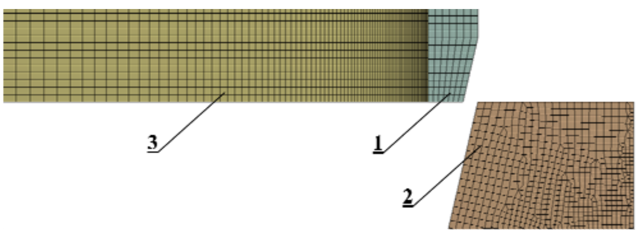

Fig.2. Meshed model: 1-semaless tube, 2-cone bushing and 3-PU foam

Fig. 2 shows meshed elements. During deformation, reaction force was measured on defined vertical stroke. Value of stroke was 210 mm (length of the seamless tube is 220 mm). Adopted value of friction coefficient, between seamless tube and cone bushing, is 0.35. This value is adopted in accordance to results [2, 8].

2.1. Material properties

Absorber were formed from semaples tube, cone bushing and PU foam filler inside the tube. Seamless tubes were made from low carbon steel in grade P235T1 with dimensions ∅219.1/δx220 mm. Parameter "δ" is a wall thickness that has different values in the numerical simulations (2.5, 4, 5.9, 6.7, 8.0 and 10.0 mm). Cone bushing were made from quench and tempered carbon steel in grade C45 with dimensions ∅220/199/13°x60 mm. Rigid PU foam was prepared by mixing liquid polyisocyanate with liquid polyol directly in the tube, what was induced bonded PU foam for the tube wall. Main material properties of tube, cone bushing and PU foam of density 175 kg/m^3 are shown in Table 1. Bilinear material model of the tube was used.

Tab. 1. Material properties

Component	Elastic modulus [MPa]	Tangent modulus [MPa]	Poisson ratio	Yield stress [MPa]
Seamless tube	2.1e5	1450	0.3	235
Cone bushing	2.1e5	-	0.3	430
PU foam 175 kg/m^3	66.1	-	0	1.4

3. RESULTS

Numerical simulations of energy absorbtion of foam filled tube absorber were performed for six different values of wall thickness and six different values of density of PU foam. First step was validation of developed numerical model using results obtained by previous research papers. After that analyses of impact of different values of tube wall thickness and foam density were performed.

3.1. Validation of developed numerical model

Fig. 3 shows force vs. stroke diagram obtained by numerical simulations and experimental investigations of empty seamless tubes with wall thickness of 5.9 and 6.7 mm. Based on this diagram can be concluded that results of experimental investigations and numerical simulations are in a good correlation. Validation of numerical model was performed for two different wall thicknesses of seamless tubes.

Fig. 4 shows samples after finished deformation process obtained by experimental investigations (a) and numerical simulations (b). At the experimental and numerical samples three characteristic zones on the tube wall show very similar shape of deformation. Very close curve of flow of force and shape of deformation between experimental and numerical model validate developed numerical model for further analyses.

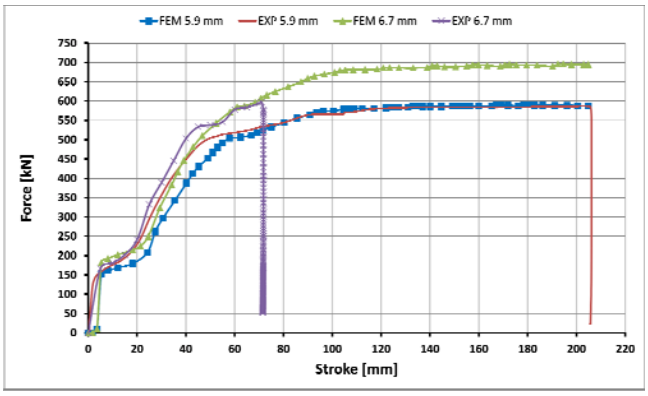

Fig. 3. Force vs. stroke diagram – validation numerical models

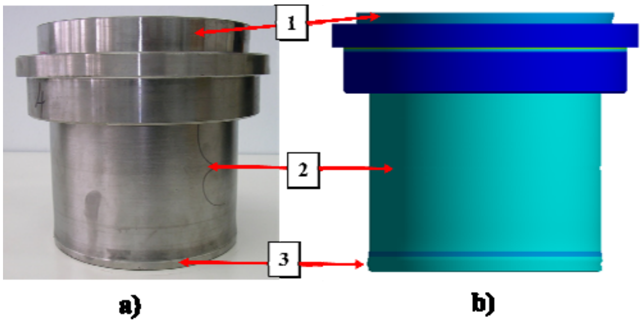

Fig. 4. Shape of deformation: a) experimental investigations and b) numerical simulations

3.2. Results of numerical simulations

After validation of developed numerical model, FEM analyses of absorption characteristics for different values of tube wall thickness and density of PU foam were done.

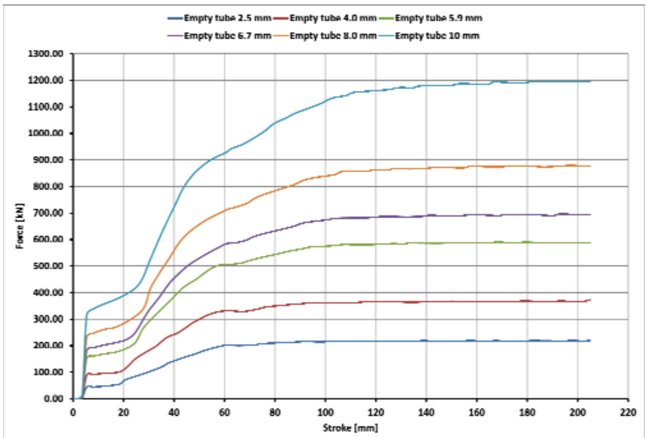

Fig. 5. Force vs. stroke diagram – empty tube

Fig. 5, 6 and 7 show force vs. stroke diagram for mentioned variation of parameters.

Using presented F(h) diagrams the main absorption parameters were calculated and formed diagrams AE/SAE vs. tube wall thickness/density of PU foam, Fig. 8-10.

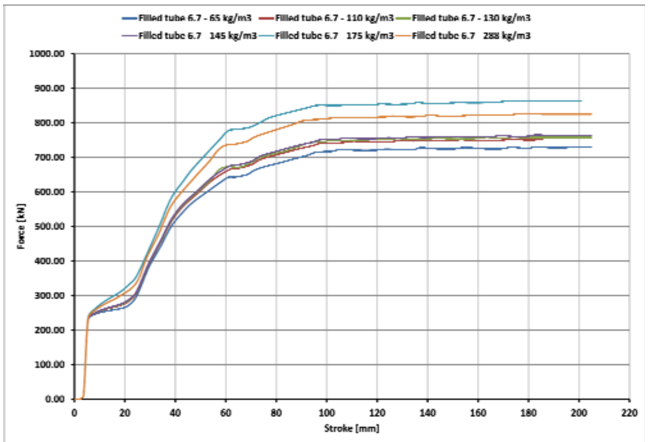

Fig. 6. Force vs. stroke diagram – foam filled tube – different density of PU foam

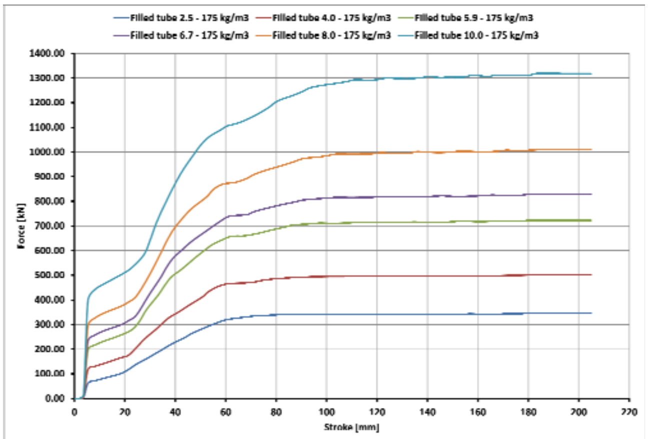

Fig. 7. Force vs. stroke diagram – foam filled tube – different density of wall thickness

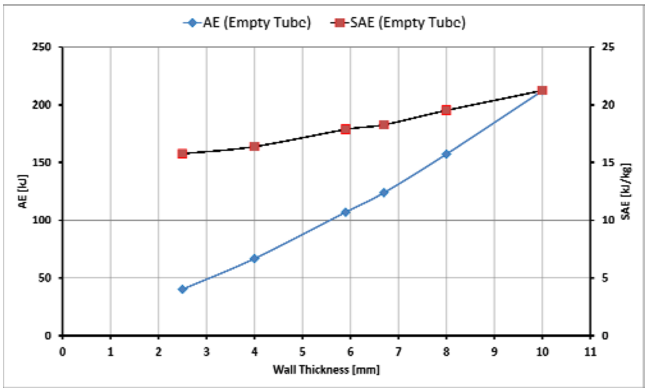

Fig. 8. AE/SAE vs. wall thickness – empty tube

In this diagram can be seen that AE significant increases with increase of wall thickness, what was expected. SAE slightly increases because increase of tube wall thickness leads to significant increase of tube mass. Fig. 9 shows similar change of AE and SAE for foam filled tube with constant density of 175 kg/m^3 and different values of wall thickness.

Fig 10. shows that increase of density leads to slightly increase of AE and decrease of SAE.

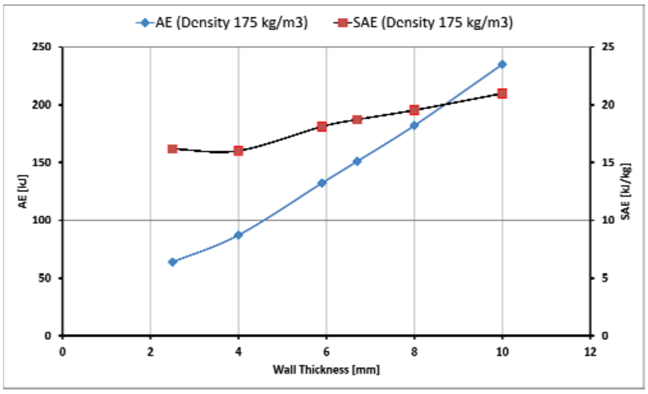

Fig. 9. AE/SAE vs. wall thickness – foam filled tube

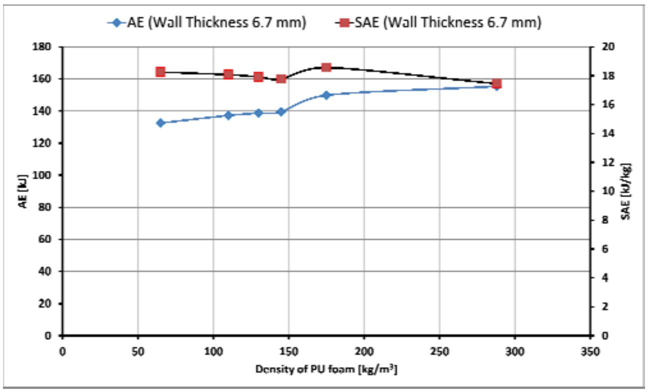

Fig. 10. AE/SAE vs. density of PU foam – foam filled tube

4. CONCLUSION

Purpose of collision energy absorber is to reduce collision consequences and to decrease injuries of passengers as well as increase safe of goods and prevent uncontrolled distortion of wagons structure. Results presented in this paper show that different parameters have lower or higher impact on absorbed energy. Change of wall thickness from 2.5 up to 10 mm can increase AE for about 5 times while change of density from 65 up to 288 kg/m^3 can increase AE for about 17%. Considering obtained results and requests for gradual introducing of force in bearing structure of wagons during collision use of rigid PU foam as a filler of tube presents very acceptable solution for fine tuning of absorption characteristic of shrinking tube energy absorber. Developed and validated numerical model in this paper can be used in design phase without need for additional experimental tests. In this way it is possible to reduce design costs in significant amount. Next step of the research of this type of absorber is to perform dynamic test of foam filled tube absorber. These results will complete the numerical model and provide opportunity for further use of it in dimensioning of foam filled absorption elements in accordance with the standard requests, without any additional experimental investigations.

ACKNOWLEDGEMENT

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ANALYSIS OF THE IMPACT OF ELECTRIC LOCOMOTIVES ON ENERGY PARAMETERS IN THE POWER SUPPLY SYSTEM

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Petar MARKOVIĆ[2]

Abstract *– Electric locomotives and electromotive trains in service on the networks of electrified railways of Serbia have a technological level, equipment for electricity conversion which covers the spectrum from the sixties of the last century to modern advanced solutions of traction and electric braking systems. The paper analyzes the feedback effects of the locomotive on the network as a generator of current harmonics, and qualitative parameters of power that the locomotive takes from the network for the cases of the diode and thyristor locomotives that are most represented in traffic and modern locomotives with four-quadrant converters and asynchronous traction motors. The results of the analysis indicate that the owner of the infrastructure within the calculation of prices has the possibility to classify the rolling stock according to type according to the impact these on the supplying network*

Keywords – Electrical Locomotives, Power factor, Power Supply System

1. INTRODUCTION

It is known that electric locomotives are nonlinear electric loads. This is a consequence of the conversion of electricity starting from the point of collection, at the connection of the pantograph with the contact wire, to the connections of the traction motors. This has the consequence that the estimate of electricity consumption based on expression (1) cannot be taken as credible because the linear relations of simple periodic currents and voltages on the alternating side do not represent an adequate and realistic state.

$$W(NT) = U_{\max} I_{\max} \sum_{k=1}^{N} \int_{(k-1)T}^{kT} \cos\omega t \ \cos(\omega t - \varphi)\, dt \qquad (1)$$

The nonlinearity of the load is manifested by the appearance of harmonic currents in line, generated by converters that affect the quality of electrical power. Several IEEE and IEC standards address power quality issues. Distorted current in the contact network with negligible inductance leads to voltage distortion, which can have negative effects on consumers sensitive to voltage or current distortion. Also, higher harmonics of currents in the network cause additional losses that are impossible to measure on the measuring devices on the locomotive that provide data on the taken active power. Fortunately, depending on the type of converter that causes complex periodic currents in the contact network, it is possible to evaluate this element of the impact of the electric locomotive on the power supply network. It is necessary to define the appropriate criteria and their quantitative value that would provide insight into the process of distortion of the power supply network parameters. In defining the criteria, we will assume that the voltage in the contact network is with negligible distortion, so its RMS value is approximated by the RMS value of the fundamental harmonic. As the current in the network is a complex periodic, expression for its current value is:

$$i(t) = \sum_{n=1}^{\infty} \sqrt{2} I_n \cos(n\omega t - \varphi_n) \qquad (2)$$

The current distortion factor is defined by the following expression:

$$DF_i = \frac{I_1}{\sqrt{\sum_{n=1}^{\infty} I_n^2}} \qquad (3)$$

From expression (3) the total current distortion concerning the sinusoidal wave is:

$$THD = \sqrt{\left(\frac{1}{DF_i}\right)^2 - 1} \qquad (4)$$

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Quantitative indicator of the influence of electric locomotive on the primary network is determined by the power factor PF which is defined by:

$$PF = \frac{UI_1 \cos\varphi}{U\sqrt{\sum_{n=1}^{\infty} I_n^2}} = DF_i \cos\varphi \quad (5)$$

2. REVIEW OF POWER ELECTRONICS TECHNOLOGIES FOR LOCOMOTIVES

Diode locomotives belong to the technological generation of the 1960s, but they still make up the majority of the fleet of domestic operators represented through series 441 and 461. Their typical structure of the traction circuit allows an identical approach to be applied for both series. The basic parameters that determine the waveform of the current in the primary network are the reactors in the traction motor circuit, the counter-electric motor force of the rotor, and the commutation of the rectifying diodes in the bridge. Thyristor locomotives are equiped with fixed turns ratio transformers. Regulation of the traction parameters is performed through control of the assymetric thyristor bridges. Thyristor locomotives, that operate in the Serbian railway network, belong to series 444. They were result of modernisation and modification of the diode four-axle locomotives, from series 441. Recently, locomotives with asynchronous traction motors are procured. They represent modern traction vehicles, with dominant technological features comparing to previously existing traction vehicles. This paper presents an analysis of the impact of the three main locomotive types on the power parameters of the catenary supply network, with power factor as main quantitve criterion.

2.1. Locomotive with diode rectifier

A very simplified approach that takes into account only the inductance of the reactor and neglects the commutation and resistance in the traction motor circuit leads to the assessment that alternating current consists of rectangular half-cycles of intensity I_M. In this case DF_i=0.9 and THD=0.4843. In this simplified case, the maximum value of the power factor is PF=0.9 with $\cos\varphi$=1.

To obtain the dependence of the power factor as a function of the active power of the locomotive in the range between (10% -100%)$\boldsymbol{P_n}$ we use the simulation approach. In this manuscript, the SIMULINK simulation package or its toolbox "SIMSCAPE POWER SYSTEMS" was used. The simulation model of the traction circuit (Fig. 1) aims to provide insight in the real forms of current in an alternating circuit that is connected via a diode rectifier to a traction motor that is modeled as an RLE circuit.

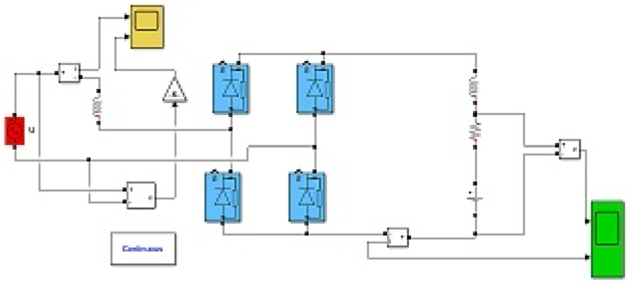

Fig. 1. Simulation model of the converter with diode rectifier

From the diagram in Fig. 2, the real waveform of the current has the characteristic slope at the change of polarity and upper and lower waveform which is a consequence of the size of the inductor in the traction motor circuit. By varying the voltage and the counter electromotive force up to the value corresponding to the maximum speed on the simulation model, the function is obtained:

$$PF = f\left(\frac{P}{P_{max}}\right) \quad (6)$$

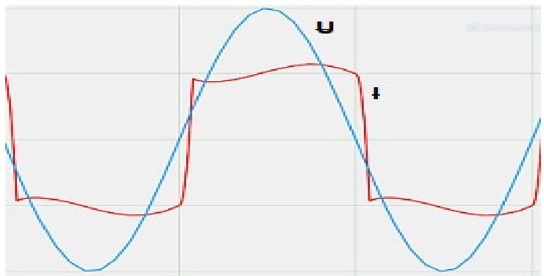

Fig. 2. Current waveform (red) in the AC terminal of the diode rectifier

2.2 Locomotive with thyristor rectifier

The development of power electronics has led to the use of thyristors or controllable rectifiers with phase control with symmetrical or asymmetrical bridge topologies

Thyristorised locomotives were created by the modernization of diode locomotives so that voltage control on the traction motor is achieved by changing the angle of the deblocking of the thyristor in the asymmetric bridge when it consists of two diodes and two thyristors. The average value of the DC voltage is a function of the amplitude of the input alternating voltage and the angle that controls the switching on of the thyristors. Although this solution has a clear advantage in terms of continuity of locomotive traction control, deteriorations in the alternating circuit are noticeable, which are quantified through the worsened power factor.

Figure 3 shows a simulation model with clearly highlighted circuits for controlling the thyristor deblocking angle and a traction energy circuit. The voltage and current characteristics on the DC and AC sides are graphically displayed using modeled oscilloscopes. Also, numerical data for determining the functional dependence are specially stored and processed in MATLAB.

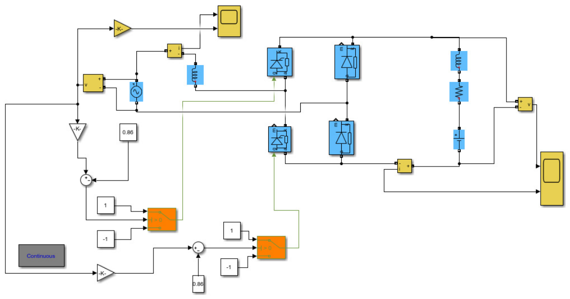

Fig. 3. Simulation model of the converter with asymmetric thyristor bridge

From the diagram of voltage and current (Fig. 4) on an AC side, the phase shift of alternating current to the voltage affects the increased delay of the fundamental harmonic of current or to the decrease of cosφ in relation to the phase shift of the fundamental harmonic of current to the voltage in the diode locomotive.

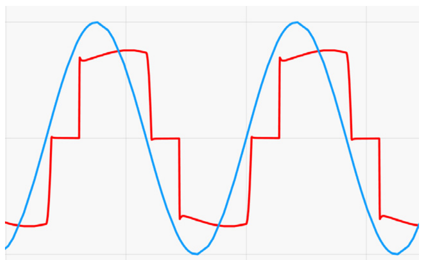

Fig. 4. Current waveform (red) on the AC side of the asymmetric thyristor bridge

2.3. Locomotive with four-quadrant converter and asynchronous traction motors

When undulated DC traction motors were replaced by three-phase asynchronous motors, the first solutions of AC/DC converters were based on symmetrical or asymmetric thyristor converters Such solutions have further increased the disadvantages related to the poor power factor and the distortion factor of alternating current, which is a measure of the deviation of the shape of alternating current from the ideal sinusoid.

These shortcomings were especially evident in the mass use of power locomotives in between (5-6 MW) because the impact on the catenary is very pronounced. Another important drawback was related to regenerative braking, which is impossible in the case of an asymmetric thyristor bridge. By applying asymmetrical thyristor bridge, the generated electric power due to recuperation was highly distorted in comparison to the power with sinusoidal values of current and voltage.

Four static switches T1…T4 is based on IGBT transistors with antiparallel diodes in the bridge configuration form the topology of the four-quadrant converter (Fig. 5). The alternating connections are M and N which connect of the transformer secondary, modelled using an alternating generator and a series-connected inductor L. The DC connections at the output of the converter are marked with P and Q. If we set the voltage-current coordinate system, the converter can work in two rectifier modes corresponding to the first and third quadrant and two inverter modes corresponding to the second and fourth quadrant. From this, we conclude that the converter has the possibility of two-direction power flow, one direction corresponds to the traction mode and the other corresponds to the recuperative braking mode, with the return of energy to the network. The inductance in series connection with the alternating voltage generator is modelled by the secondary of the traction transformer. The capacitor on the DC side has the role of damping the voltage pulsations by providing a constant voltage at the input connections of the voltage inverter for supplying the traction motors.

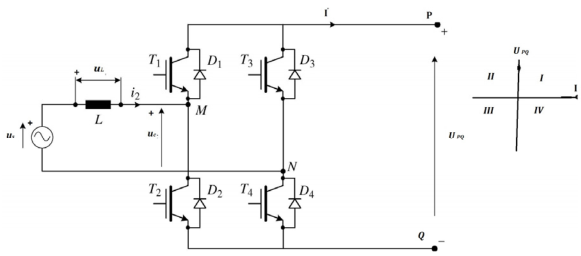

Fig. 5. Scheme of the four-quadrant converter

An important and first task that the converter has to fulfill is that the fundamental component of the current that the vehicle takes from the catenary has a power factor cosφ = 1. The second refers to the optimization of the alternating current distortion factor which measures the distortion in relation to the sinusoidal current. This goal is met by pulse width modulation, i.e. by conveniently varying the on time of static switches in the bridge branches forming a current close to the sinusoid (Fig. 6).

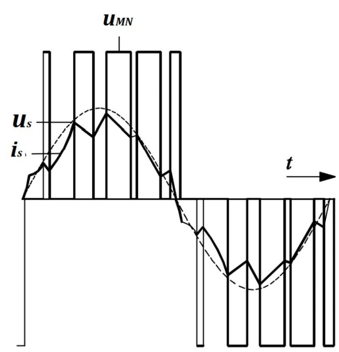

Fig. 6. Current waveform from the AC power network, obtained by PWM in four-quadrant converter

Comparative rewiev of the functional relation given with (6) for the analyzed locomotive types is given in the Fig. 7.

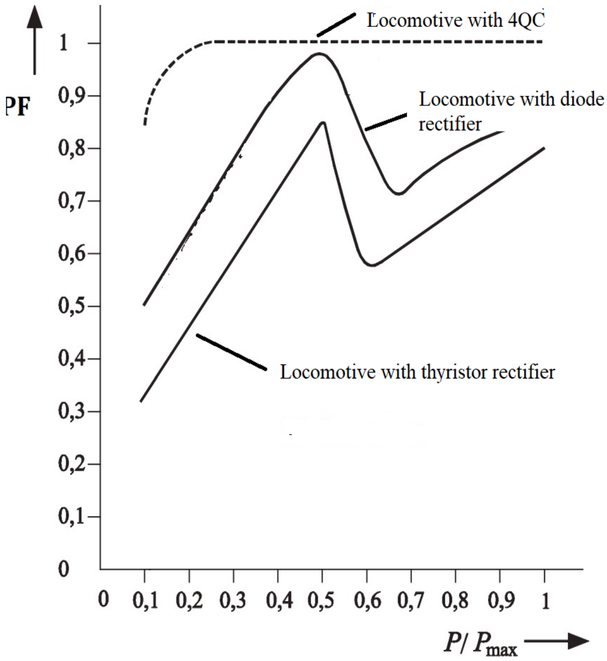

Fig. 7. Dependence of the power factor of the analyzed locomotive types on the relative active power

3. CONCLUSION

It is shown that various types of traction vehicles have a significantly different impacts on RMS current and distortion factor. Based on the presented comparative analysis, the conclusion is that a part of the transport cost on the electrified railway lines may be tied to a power quality coefficient, taking account the maximal power factor as a criterion.

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INFLUENCE OF HEAD WIND ON THE BRAKING DISTANCE OF SINGLE RAILWAY VEHICLE

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Abstract *– Train stopping distance during brake application is influenced by the brake system performance, longitudinal running resistance and presence of wind and its direction. This paper deals with influence of the wind conditions on the results of slip brake tests. The influence is more expressed in the case of single vehicles tests and less expressed for the trains. The tests with and without presence of head wind were performed on the tank car type Zacns. Depending on wind speed, measured stopping distances may differ significantly. Opposite from head wind, tail wind increases stopping distance and should be considered when calculating safety margin and setting service train speed depending on the wind conditions. The results may also serve for further analyses of aerodynamic characteristics of railway vehicles and for verification of numerical simulations.*

Keywords – stopping distance, slip brake tests, head wind, influence

1. INTRODUCTION

Influence of wind on railway vehicles can be considered from several aspects. As an effect influencing safety and stability of vehicles and as an effect that affects train running resistance and stopping distance. This paper deals with influence of the wind on the braking distance of the train during running service and influence on the test results during slip tests and measured stopping distance of single bogie wagon. Wind presence may cause these test results to be irregular. UIC 544-1 [1] describes regular atmospheric conditions as with the minimum wind and with dry rails. Influence of wind on the brake performance test is reported in [2] but without any binding limit values prescribed.

2. BRAKE PERFORMANCE TEST

This chapeter presents regular brake perfomance test methodology in the case of basic bogie wagons. That means without presence or with the minimum wind. Full scale test [3] was performed with single tank car type Zacns with K-block brake (Fig 1). When empty this wagon runs at 120 km/h and in the fully loaded conditions the maximum speed is 100 km/h.

Fig.1. Tank wagon Zacns

2.1. Test procedure

Determining the braking performance for freight wagons with top speed up to 120 km/h and K-brake blocks is performed with single vehicle slip tests [1]. The tested vehicle is accelerated up to the speed envisaged for braking. At this speed, an emergency (rapid) brake shall be applied, at the same time or short time after wagon uncoupling from the test train composition. The test speed for freight wagons with top speed up to 120 km/h is 100 km/h and 120 km/h. At least four valid tests shall be carried out at each test

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speed. The mean value of stopping distance shall be corrected for nominal test conditions and then braked weight percentage is determined using assessment graphs or formulae given in UIC [1].

2.2. Measuring equipment

During slip tests following braking parameters vs. time were recoreded:

- wagon speed;
- stopping distance;
- main brake pipe pressure and brake cylinder pressure.

Table 2 presents high perfromance measuring equipment used for these purposes.

Tab. 2 Measurement equipment

Item	Type	Manufacturer
Pressure tranducer	P8AP	HBM
	P8AP	HBM
Radar doppler transducer	Delta DRS1000	GHM Engeen.
Data aquisition system	Quantum MX840A	HBM
Contact thermometer	905-T2	TESTO
Notebook PC	E734	Fujitsu

Weather station (Fig. 2) served for checking the test conditions regularity. This station records: environmental remperature, atmospheric pressure, air humididty, wind speed and direction.

Fig.2. Weather station position

3. CORRECTING THE STOPPING DISTANCE

3.1. Correcting the measured stopping distance

The stopping distance obtained in test shall be corrected in order to take into account the following factors:

- nominal speed in relation to the initial speed measured in the test;
- gradient of the test track.

3.2. Correction of the mean stopping distance

After determining the mean stopping distance, its validity is checked using following statistical criteria that should be met at the same time:

Criterion K1: $$\frac{\sigma_n}{\bar{s}} \le 0.03 \quad (1)$$

Criterion K2: $$\left| s_e - \bar{s} \right| \le 1{,}95 \cdot \sigma_n \quad (2)$$

where:

$$\sigma_n = \sqrt{\frac{\left| s_j - \bar{s} \right|^2}{n}} \quad (3)$$

s_j [m] – stopping distance measured during test "j" and corrected using Formula (4) , expressed in m,
n [-] – number of valid test
σ [-] – standard deviation of test results;
$\bar{s}$ [m] – mean stopping distance, expressed in m;
s_e [m] – individual stopping distance furthest from mean value.

The next step is correction of the mean stopping distance by following criteria:

- basic principle - adaptation of the existing condition of the test vehicle to the actual characteristics of design series,
- additional correction - the actual filling time shall be corrected in relation to the nominal value.

$$s_{corr} = t_e \cdot v_{nom} + \frac{F_{test} + W_m}{F_{corr} + W_m} \cdot (\bar{s} - v_{nom} \cdot t_e) \quad (4)$$

$$t_e = t_o + \frac{t_s}{2} \quad (5)$$

$$F_{test} = m \cdot \rho \cdot \frac{v_{nom}^2}{2(\bar{s} - v_{nom} \cdot t_e)} - W_m \quad (6)$$

$$F_{corr} = F_{test} \cdot \frac{\eta_{dyn}}{\eta_{dyn,test}} \cdot \frac{d_{test}}{d_m} - \left[\frac{p_{nom} - p_{feder}}{p_{test} - p_{feder}} \right] \quad (7)$$

s_{corr} - corrected mean stopping distance [m],
$\bar{s}$ - mean stopping distance of test [m],
t_e - equivalent time for development of brake force [s],
t_s - mean measured brake cylinder filling time [s],
v_{nom} - nominal initial speed during tests [m/s] ,
F_{corr} - corrected brake force [kN],
F_{test} - mean brake force during the test [kN],
W_m - mean value of resistance to forward movement (on the straight track and without wind presence) [kN],

d_{test} - mean wheel diameter on test wagon,
d_m - diameter of semi-worn wheel [mm]; for block brakes d_m=d_{test}
η_{dyn} - mean efficiency of brake rigging during journey,
$\eta_{dyn,test}$ - efficiency of brake rigging during test,
p_{nom} - nominal brake cylinder pressure,
p_{test} - brake cylinder pressure on test vehicle,
p_{feder} - pressure of retaining springs relative to the effective brake cylinder piston surface area,
v_o - initial braking speed [m/s].

The mean value of resistance to forward movement W_m is represented by a formula (8):

$$W_m = F_{Ra,m} = A + \frac{2}{3} \cdot B \cdot v + \frac{1}{2} \cdot C \cdot v_0^2 \quad (8)$$

which consists of:

- one term independent of vehicle speed;
- one term proportional to the speed, dealing mostly with the mechanical components resistance (train and track);
- the third term proportional to the square of the speed (aerodynamic resistance), where

A, B. C are specific coefficients depending on vehicle type according to [4] or obtained by measurement [5].

4. RUNNING RESISTANCE

Running resistance is total force acting on a train against its direction of travel. It consists of several components: mechanical resistance, aerodynamic resistance, grade resistance and inertia resistance. Grade and inertia resistance are partially recoverable during train motion. Mechanical resistance is mainly due to wheel rolling on the rail (increases during curves negotiation). Aerodynamic resistance is proportional to the square of the speed and is additionally influenced by wind speed and its direction. Assuming that for one wagon tested on the same track section all test conditions are the same, this paper focuses on presence or absence of wind against vehicle travel direction.

Running resistance of freight trains is reported in [6]. Running resistance of passenger coaches was analyzed in ORE C179 [7]. Hara 1967 in Japan investigated influence of the aerodynamics on high-speed Shinkansen trains [8]

Running resistance is possible to determine using different test methods:

1. Tractive effort methods,
2. Dynamometer drawbar methods,
3. Coasting methods [5].

For assessment of wind drag during slip test the most appropriate method is Coasting method. This method implies that the wagon or train is accelerated to a certain speed. Then the traction power and brakes are switched off and from that moment starts recording of speed vs. time on the track section without gradient or with known gradient along tracks. Coasting train will start to reduce speed and kinetic energy. Decelerations calculated from the speed vs. time function serves for estimation of train running resistance. Also, it is possible directly to measure longitudinal deceleration vs. time for this purpose.

5. AERODYNAMIC RESISTANCE CAUSED BY WIND

Apart from the aerodynamic resistance included in the total running resistance, additional force acting on the vehicle is induced by wind blowing on the vehicle frontal side. Head wind generally helps braking system and decreases stopping distance. Opposite, tail wind increases stopping distance. The following formula calculates drag force [9]:

$$F_D = \frac{1}{2} \cdot \rho \cdot A_f \cdot C_D(\beta) \cdot v_{rel}^{\ 2} \quad (9)$$

In the case of direct head wind (β=0°):

$$F_D = \frac{1}{2} \cdot \rho \cdot A_f \cdot C_D(0°) \cdot (v_n + v_{wind})^2 \quad (10)$$

where:
ρ - air density [kg/m^3] ,
C_D - air drag coefficient [kg/m^2],
β - yaw angle of wind [°],
A_f - drag area [m^2],
v_{rel} - relative wind speed [m/s],
v_{wind} - wind speed [m/s],
v_n - nominal initial speed at test start [m/s].

Use of this equation for additional wind resistance, requires third term in the equation (8) to be excluded and replaced with equation (10).

Head wind with magnituded v_{wind} = 7 m/s reduces calculated stopping distance for about 7 m from v_n=100 km/h and from speed v_n=120 km/h it reduces stopping distance for 13 m.

6. TEST RESULTS

This analysis focuses on pure head wind. The yaw angle β between wind direction and train travel direction during experiments was less than 6° and could be neglected. In total, consequent side component of the wind force may cause additional running resistance related to mechanical components, but this was not included in the analysis.

This paper deals only with head wind component, considering that all other influences are known and equal during all tests. The main difference is presence or absence of wind. One series of tests was performed without wind and one with head wind having magnitude 7 m/s.

Table 3 presents test results for stopping distance in the case of wind presence and absence [0].

Tab. 3. Measured stopping distance

Initial speed (km/h)	Stopping distance (m)	
	Wind 7 m/s	No wind
100	337.44	370.25
	340.86	378.33
	340.03	381.18
	342.19	350.66
120	473.22	507.97
	471.37	526.99
	476.16	508.62
	479.67	515.50

Table 4 presents hypothetical difference in estimation of the brake performance, if the wind influence was neglected.

Tab. 4. Corrected stopping distance, brake weight percentage and brake weight

Initial speed (km/h)	Wind 7 m/s			No wind		
	s_{corr} (m)	λ (%)	B (t)	s_{corr} (m)	λ (%)	B (t)
100	373.6	131.4	28.6	400.8	121.8	26.6
120	525.9	140.0	30.5	579.9	125.2	27.3

Test results show that in the case of Zacns tank wagon, head wind with magnitude $v_{wind} = 7$ m/s reduces stopping distance for about 27 m from initial speed v_n=100 km/h and from speed v_n=120 km/h for about 54 m. Consequently, determined brake weight B, if the wind was neglected, differs for 2-3 tonns, which is unacceptably false result.

7. NUMERICAL SIMULATIONS

There are many computer programs around the world dealing with train resistance simulations. They are power tools, serving for estimation of the energy consumption, determining trains running time etc. The computer programs specialized for running resistance including aerodynamic forces, use CFD and include wind magnitude, wind yaw angle, wind speed distribution, flow around the vehicle [5, 9]. These programs may help solving different problems and performance of vast number of simulations.

8. CONCLUSION

Wind causes additional running resistance force that acts on the vehicle. In order to obtain reliable indicators of the validity of applied analytical expressions and numerical simulations, more experimental tests are needed under different wind magnitudes and directions of blowing.

Difference between the calculated and measured stopping distances identified during this research, requires further investigations. According to test results, wind influence is greater than it shows the calculations. Newer editions of valid European standards [4, 5], for any further analyses related to aerodynamics, suggest use of CFD and experimentally determined resistance coefficients for each vehicle and not to use coefficient from the database for similar vehicles [10].

As required in reference standard [1], when testing brake performance, the influence of wind should be excluded, by choosing test site and time of the test without presence of wind. Presence of wind will further complicate already complex procedure for correcting measured stopping distance and reduce reliability of measurements.

Based on the available informations from railway practice and service, significant problems related to wind influence on braking process are not reported.

ACKNOWLEDGEMENT

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SPECIFIC ASPECTS OF THE RAIL VEHICLE PASS-BY NOISE MEASUREMENT

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Vojkan LUČANIN[3]

Abstract *– Actual European legislative (NOI TSI) urges for quitter rail vehicles requiring obligatory assessment of noise emitted by rail vehicles within vehicle approval procedure. After survey of different rail vehicle noise emission scenarios, this paper discusses more in detail specifics of the pass-by noise measurement. The requirements of the measurement procedure from applicable standards are presented and discussed on the example of the tank wagon pass-by tests. Under several parameters that can influence measurement, for vehicle approval is important to measure and check if the most influencing parameters related to track lies in specified limits. If so, the measured noise emission level mainly represents the vehicle contribution and allows comparability to noise emission measurement of other vehicles. Two main track characteristics have to be measured and assessed: acoustical rail roughness and track decay rate. In the paper are presented both measurements that are more demanding than the noise emission measurement itself.*

Keywords – rail vehicles, pas-by noise, measurement, rail acoustic roughness, track decay rate

1. INTRODUCTION

Growing public sensitivity to environmental problems, especially in densely populated areas in Europe, have led to the proliferation of noise regulations [1], [2]. One of the most challenging railway noise areas are the freight wagons. In densely populated areas in some countries, noisier wagons may be exposed to noise-differentiated infrastructure usage fees, or even banned in night trains.

Noise originated from rail vehicles has two basic aspects: noise inside the vehicle and noise emitted by rail vehicles into the environment. Noise inside the vehicle is observed from the point of view of passenger comfort [3] or exposure of train driver to noise [4].

Noise emitted into the environment has following aspects [5]:

- stationary noise (also known as parking noise),
- constant speed noise (pass-by noise),
- acceleration noise (starting noise),
- braking noise.

Every aspect of noise from rail vehicles has sources from the train movement or from the vehicle equipment operation. The train movement generates rolling noise and aerodynamic noise. Rolling noise is mainly caused by rail and wheel roughness. Further noise generators are wheel flats, rail joints, local sources as switches, crossings, wheel squeal in curves, steel bridges etc. For high-speed vehicles, aerodynamic noise makes important noise component.

Operation of equipment on rail vehicles determines stationary and acceleration noise.

Any aspect of the noise abatement requires reliable test methods. The following consideration relates to some specific aspects of pass-by noise measurement illustrated using examples for pass-by noise measurement of Zacns tank wagon [6].

2. GENERAL CONDITIONS OF PASS-BY NOISE TEST

In order to obtain reliable, reproducible and comparable noise measurement results, it is necessary to measure significant influencing quantities and keep them within some acceptable limits. This includes acoustical neutrality of the test site, environmental conditions, track conditions and vehicle conditions.

The test track must not significantly affect the measurement of noise emitted by the vehicle and shall enable maximum test speed. The test section should be straight or with big radius, shall have a consistent superstructure over a minimum length of twice the microphone distance to either side. This includes

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geometry of the line, track quality, acoustic rail roughness and track decay rates.

Track superstructure should be a track with ballast bed and wooden or reinforced concrete sleepers without any type of rail or track shielding. The ballast shall be loose i.e. not bound together.

The measuring section shall be laid without rail joints, shall be free of visible defects and without audible impact due to welds or loose sleepers.

The test site shall allow free sound propagation. The level of the ground surface shall be within 0 m to −2 m, relative to the top of rail, test area shall be free of other tracks, of sound absorbing matter (snow, tall vegetation...) and free of reflective covering (water, ice, tarmac, concrete...). No absorptive material shall be added to the propagation path.

Test persons shall be in a position behind microphone that does not influence the measured sound pressure level significantly. An area around the microphones within radius at least three times the measurement distance shall be free of large reflecting objects (barriers, hills, rocks, bridges or buildings).

Meteorological conditions in normal measurement situation have relatively small influence on measurement results, so no correction of the results is required, but they can be taken into account in the assessment of measurement uncertainty.

Meteorological conditions shall be recorded: wind speed and direction at the level of the microphone, temperature, humidity, barometric pressure and precipitation. Heavy rain or wind speed higher than 5 m/s are not allowed as they may affect test results.

Two main track parameters must be measured: acoustical rail roughness and track decay rate.

3. ACUOSTICAL RAIL ROUGHNESS MEASUREMENT

The acoustical rail roughness is defined by following equation:

$$L_r=10\cdot log\left(\frac{r_{RMS}^2}{r_o^2}\right) \quad (1)$$

L_r is the acoustic roughness level in dB,

r_{RMS} is the root mean square roughness in μm,

r_o is the reference roughness; r_o = 1 μm.

Measurement was performed according to the procedure given in [7] along rolling band of both rails. The rolling band can be regarded as shiny part on the head or can be determined by traces obtained by passing of the tested wagon over the artificially colored part of the railhead. Referent width w_{ref} is 5 mm narrower at each side than rolling band, as shown in figure 1, taking into account that typical wheel-rail contact is approximately 10 mm wide.

Position of the central line of referent surface d_{ref} is measured from outer (not worn) surface of each rail. Roughness measurement should be performed along 1 central line if the $w_{ref} \leq 20$ mm, along three lines each 5 mm apart for w_{ref} between 20 and 30 mm and along three lines each 10 mm apart if $w_{ref} > 30$ mm.

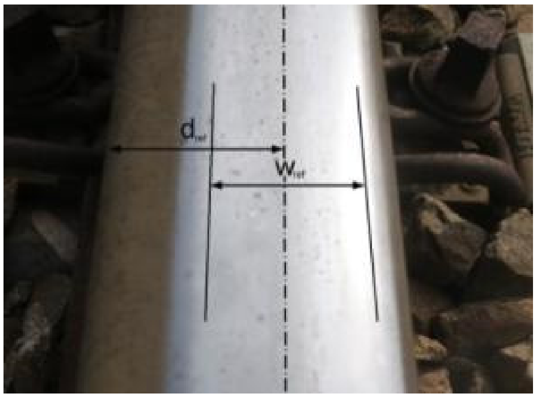

Fig. 1. Referent width of the rolling band

For the Zacns wagon test, the rolling traces were taken on beginning and on the end of the test zone. Taking into account average rolling band center position and maximum reference width, roughness measurements were made along three parallel lines 5 mm apart on each rail.

Fig. 2. Roughness measurement

Measurements were performed over the entire test section of 15 m length using device "m rail trolley", of the Müller-BBM rail technologies, Germany (figure 2), that meets requirements of [7]. Signal processing includes removal of spikes, curvature processing, that takes into account typical radius of the wheel contacting with rail and determination of 1/3 octave band spectrum for each of six samples.

The results are shown in figure 3. Lines correspond to lateral position of samples, three per each rail. For the approval of the freight wagon noise emission, the rail roughness should be below maximum limit curve shown in figure 3 as "TSI/ISO 3095:2010", in order to noise measurement results designate as comparable.

The measured values slightly exceed the upper limit. Consequently, test results of the noise emission cannot be compared to other "comparable" measurements, but are still acceptable if the measured noise level remains within limits for pass-by noise.

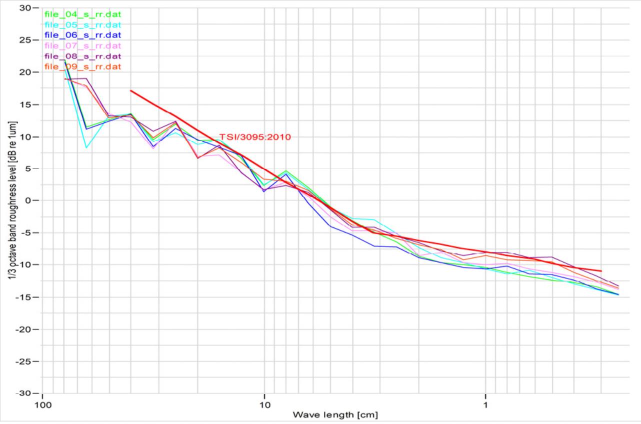

Fig. 3. Rail roughness 1/3 octave band spectra for left and right rail

4. DYNAMIC PROPERTIES OF THE TEST TRACK

The dynamic properties of the track have been evaluated in accordance with [8]. They are based on an estimate of the mechanical vibration decay rates (DR) along the rails in the one-third octave frequency band between 100 Hz and 5000 Hz. The values should lie above the lover limit curve given in [2].

The decay rates are determined on the basis of a frequency response functions (FRF) at the impulse hammer application point (direct FRF) and a certain number of FRF measurements along rail relative to the position of the excitation point (transfer function).

Fig. 4. Instrumented hammer impact for direct FRF

An instrumented hammer with a steel tip was used to excite the rail in vertical (figure 4) and transverse direction. An accelerometer fixed to the rail in the vertical and the other in the lateral direction measured the corresponding response for each direction.

First, the initial accelerometer position was sought in the middle of two sleepers near one end of the test section. Three positions were checked for each rail. If the results show similarity of the obtained direct FRFs for each impact direction, one of the three positions can be used as the accelerometer position for all measurements at one rail.

The full set of FRF was measured in the vertical and transverse directions on the right and left rails with force impact applications at various distances x from the accelerometer across the test section, as shown schematically in figure 5.

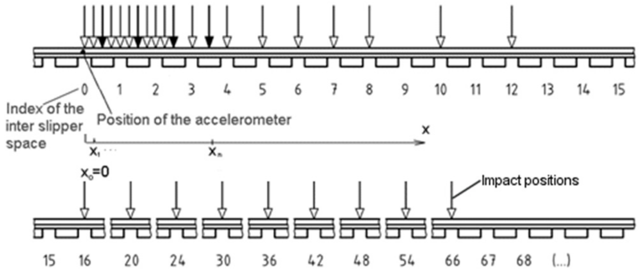

Fig. 5. Grid of the excitation points

The measurements were carried out to the point for which the response was at least 10 dB lower in each one-third octave band than direct FRF (obtained at x=0). It was necessary to make measurements up to distance x_{max} = 21,6 m.

An average FRF of 4 validated impulses were taken into account for each elementary FRF. The quality of each FRF measurements was checked using coherence function.

The decay rates (DR) of the vertical and transverse bending waves as a function of the distance are calculated based on these sets of FRF measurements in each one-third octave band using the following formula [8]:

$$DR=\frac{4,343}{\sum_{x=0}^{x_{max}}\frac{|A(x_n)|^2}{|A(x_o)|^2}\Delta x_n} \qquad (2)$$

Here is:

$A(x_o)$ FRF at position x=0 (direct FRF) in regarded one-third octave band,

$A(x_n)$ FRF at position x_n along the track (transfer FRF) in regarded one-third octave band,

Δx_n – distance between the points situated at half-distance between the measuring positions on either side of the excitation position n.

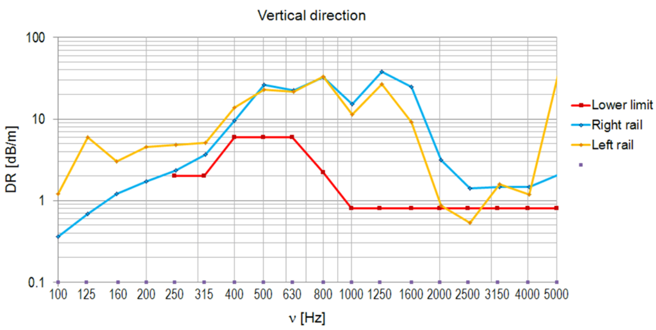

Fig. 6. Track decay rate in the vertical direction

Figure 6 shows the calculated track decay rates for left and right rail in vertical direction. In the 1/3 octave band of 2500 Hz the decay rate is below lower limit, making further noise emission test results "non-comparable".

5. PASS-BY NOISE MEASUREMENT

For the pass-by noise test was used composition consisting of locomotive, one 98 m^3 Zacns tank wagon and one 87 m^3Zacns tank wagon, figure 7. These two tank wagons have identical design and only differ in length.

Fig. 7. Test composition pass measurement point

At least three measurements at 80 km/h ±5% and three at v_{max} =120 km/h ± 5% should be performed. The microphone is positioned at 7,5 m of track axis and 1,2 m above top of rail.

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:

$$L_{pAeq,T_p} = 10 \cdot log\left(\frac{1}{T_p}\int_0^{T_p}\frac{p_A^2(t)}{p_o^2}dt\right) \quad [dB] \qquad (3)$$

where:

T_p is the measurement time interval in s;

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

p_o is the reference sound pressure; p_o = 20 µPa

During the pass-by of the test train the A-weighted sound pressure level was continuously measured as a function of time. Each wheel position vs. time relative to microphone, was detected using an optical sensor fixed close to the rail and aligned with microphone. From this signal, is calculated actual speed of the train and moments of passing middle of the first and second tank wagon T_1 and, which enabled integration of $L_{pA}(t)$ in time interval $T_p = T_2 - T_1$ in order to get L_{pAeq,T_p}.

The test procedure includes calibration of microphones and background noise measurement, measured at the beginning of the test, checking of acoustical neutrality of neighboring vehicle (locomotive in this case), normalization to speed of 80 km/h, and to specific wagon length per axle according to formula:

$L_{pAeq,Tp(APLref)} = L_{pAeq,Tp(vtest)} - 10 \cdot log(APL_{wag} /0{,}225\ m^{-1}) - 30 \cdot log(v_{test} /80\ km/h)$

Here is: $APL_{wag} = \frac{n}{L_{OB}}$, n is number of axles, L_{OB} is length over buffers and v_{test} is actual speed during the measurement.

Figure 8 shows an example of $L_{pA}(t)$ during the pass-by test at 120 km/h. The red line indicates the passage of each wheel of the composition.

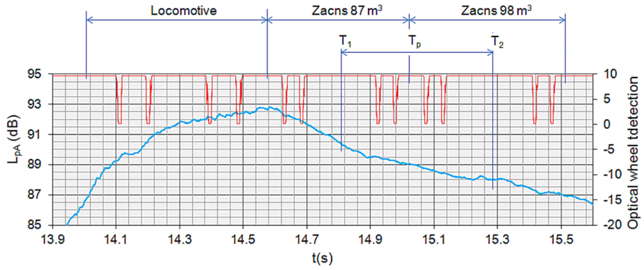

Fig. 8. Example of sound pressure level record

After normalization, for assessment, the arithmetic mean of the series of measurements is rounded to the nearest integer decibel. For the Zacns wagons, the determined value of 83 dB was right at the upper permissible limit.

4. CONCLUSION

Pass-by noise measurements of rail vehicles require careful search for the suitable test section to obtain comparable results. Poor track acoustical characteristics like track roughness and track decay rate may amplify pass-by noise beyond the allowable limits. Achieving the relevant track characteristics requires more effort than the noise measurement itself.

ACKNOWLEDGEMENT

Authors express gratitude to Ministry of Education, Science and Technological Development of Republic of Serbia for allocated funds.

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XIX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS RAILCON '20

NUMERICAL ANALYSIS OF WAGON LEAF SPRINGS

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Abstract *– This paper deals with the methodology of analysis of the leaf springs of the freight railway wagons by using modern software packages. The methodology is applied in a concrete example of leaf spring for axle load of 200 kN. The procedure of forming the CAD model of the leaf spring using AutoCad and Solid Works is exposed, as well as the development of numerical model in Ansys software package. The results of the static and dynamic analysis of given leaf spring are presented and commented. Comparison with the results of analytical calculation has shown the validity of the developed model. In this way, the proposed methodology can be successfully used in the design of various types of leaf springs in engineering practice.*

Keywords – Leaf Spring Calculation; FEM Analysis; Railway Vehicles; Freight Wagons.

1. INTRODUCTION

The suspension system of the railway vehicles is usually based on the helical or leaf springs. The advantages of helical springs are relatively small dimensions and good elastic properties, so they require less space for installation. In case of their usage, the additional elements for damping of oscillations must be installed in suspension system of railway vehicles. In contrast, leaf springs have both elastic and damping behaviour, while they need something larger space for installation. In any case, both solutions are widely used in suspension systems of railway vehicles, while the leaf springs are the subject of interest in this paper.

Fast design and calculation of the leaf springs of railway vehicles is very significant in engineering practice. In this sense, the advanced and modern software packages provide large possibilities [1–2]. The modern approach comprise the development of numerical models based on finite element method (FEM) that provide performing the static and dynamic analysis of these elements [3–4]. Consequently, this paper deals with one of the approaches in the design and analysis of leaf springs of railway vehicles by using a modern software packages.

2. CONSTRUCTION OF LEAF SPRINGS

The leaf springs are the oldest elastic elements composed of more steel leafs that are connected by spring buckle. During the exploitation, it is deformed, while between leafs there are mutual friction that damping the oscillations. The complete of leaf spring is composed of the main leaf (with eyes), other leafs, spring buckle and wedge. Leafs are made of steel tapes which are bend in certain radius and subjected to the thermal treatment. Every leaf has on its upper side the longitudinal groove and on bottom side the appropriate longitudinal rib, which prevents mutual lateral movement of the leafs. The main leaf has on its ends the eyes for connection with the wagon underframe or bogie frame. The characteristic construction and dimensions of the leaf spring are shown in Fig. 1.

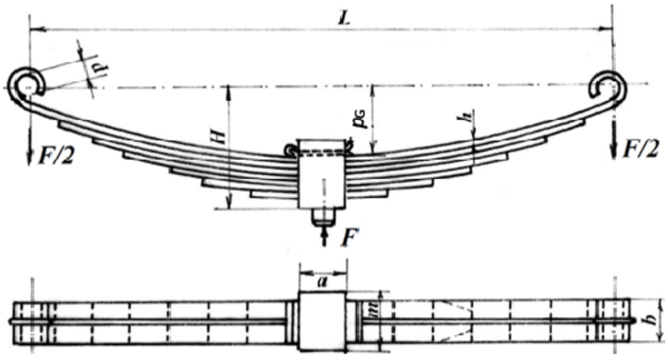

Fig. 1. The characteristic construction and dimensions of the leaf spring [5]

The characteristic dimensions of the leaf spring are (Fig. 1): L – length (distance between ears centers in unloaded condition); d – inner diameter of ear; p_G – camber (distance from the upper side of the main leaf and the line that pas through eyes centers, in the

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middle, in unloaded condition); and H – height of the leaf spring (distance from bottom side of spring buckle and the line that pas through eyes centers, in the middle, in unloaded condition). Under the vertical load, the values of the camber of the leaf spring is decreased, and the difference between the camber in unloaded and loaded condition is the deflection of the leaf spring. During the running of the railway vehicle, value of the camber oscillates around the equilibrium position (the value of the camber under the static load of the leaf spring). The frequency of these oscillations is important for stress state, especially for the fatigue and life of the leaf spring.

3. LOAD CASES FOR LEAF SPRING CALCULATION

On the basis of additional parameters for every concrete case, such as mass of the empty wagon, mass of the wheelset, number of axles, number of leaf springs, etc., by a certain methodology, three characteristic load cases can be defined. For leaf spring for axle load of 200 kN considered in this paper, the specific load cases are calculated in [5], and those are:

- Load case 1: The load of the leaf spring under empty wagon (F_k=17.8 kN),
- Load case 2: The load of the leaf spring under fully loaded wagon (F_t=91.55 kN),
- Load case 3: The load of the leaf spring under fully loaded wagon in the dynamic regime (F_{max}=119 kN).

Beside this, the geometry of the considered leaf spring is defined in [5]. The required stiffness, dimensions, number of leafs, stresses and safety factor, are determined. The defined geometry and the previous load cases are used for demonstration of procedure of analytical calculation of the leaf spring, as shown in the next chapters.

4. FORMING OF CAD AND FEM MODEL

The first step is modelling the main leaf in 2D surrounding, for which AutoCAD is the most favourable, and it is used in this case. In this way, the sketch for importing into 3D software is formed, as shown in Fig. 2. It is important to take into account the importance of proper geometry measures for the unloaded leaf spring as well as location of the coordinate system.

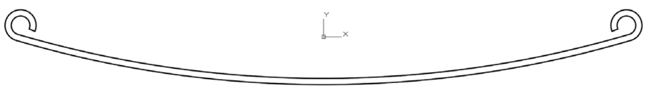

Fig. 2. The sketch of main leaf formed in AutoCAD

In next phase, formed dwg or dxf file with sketch is imported in software for 3D modelling - in this case SolidWorks is used. After this, it is very simple to obtain 3D geometry of main leaf, as shown in Fig. 3.

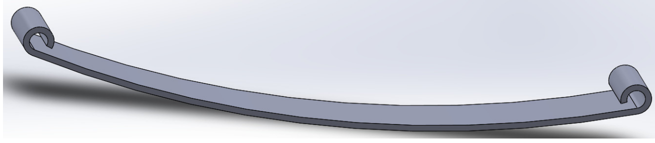

Fig. 3. The 3D geometry of main leaf formed in SolidWorks

The main leaf modelled in this way is basis for modelling the first next leaf, first as sketch in AutoCAD and after that as 3D model in SolidWorks (after importing the sketch). Therefore, this procedure is repeated as many times as there are leafs of the leaf spring. The CAD model is ended after the last leaf is modelled. The finally formed CAD model of the considered leaf spring is shown in Fig. 4.

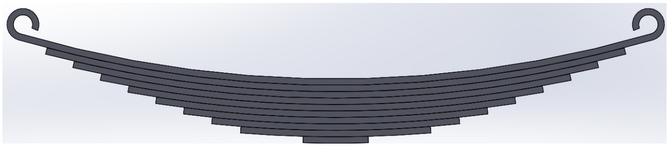

Fig. 4. The finally formed CAD model of the considered leaf spring in SolidWorks

The basis for forming the FEM model is previously formed CAD geometry which is imported in Ansys in form of IGES or STEP file. The values of parameters of the leaf spring material (spring steel 51Si7) are introduced: E=20000 kN/cm^2 – Modulus of elasticity, R_e=110 kN/cm^2 – Yield strength, R_M=130 kN/cm^2 – Ultimate strength and σ_D=70 kN/cm^2 – Endurance limit. In the next phase, supports are adjusted, as shown in Figs. 5-7.

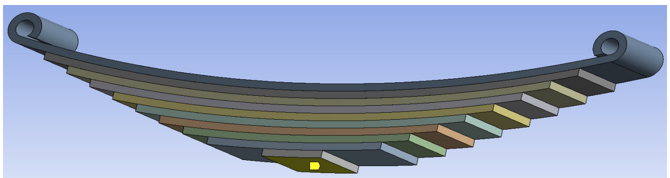

Fig. 5. Support 1. – only vertical translation allowed

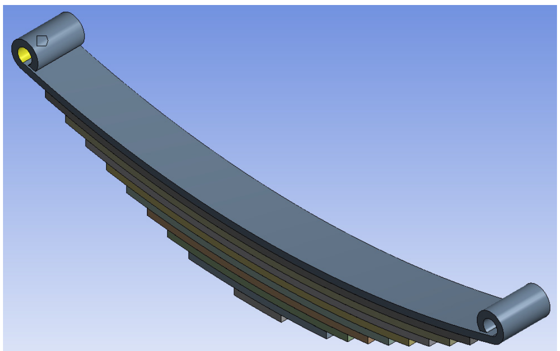

Fig. 6. Support 2. – rotation and horizontal translation allowed

The finally generated FEM model is composed of 28158 finite elements and 109598 joints (Fig. 8). It is important to note that connections between leafs are defined with command "no separation".

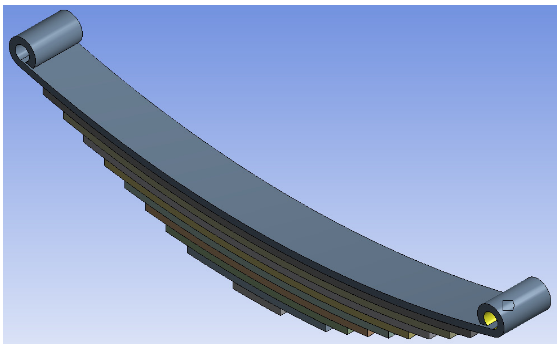

Fig. 7. Support 3. – rotation and horizontal translation allowed

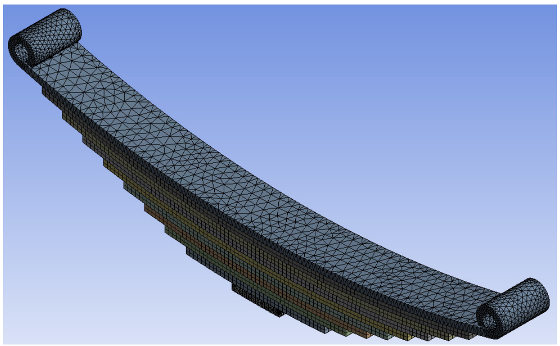

Fig. 8. The finally formed FEM model of the considered leaf spring in Ansys

At the end, previously defined three load cases are adjusted. The applied force for third load case is shown in Fig. 9.

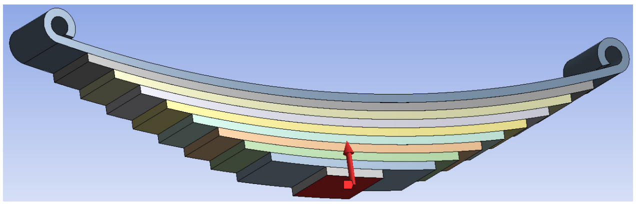

Fig. 9. The applied force for third load case

5. RESULTS OF FEM CALCULATION

The obtained results for given load cases are shown in Figs. 10-15.

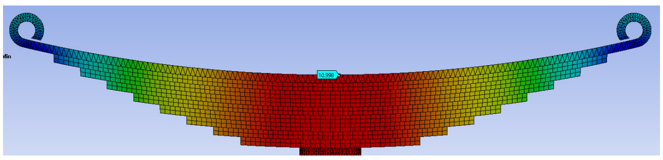

Fig. 10. The deflection for load case 1 (1.1 cm)

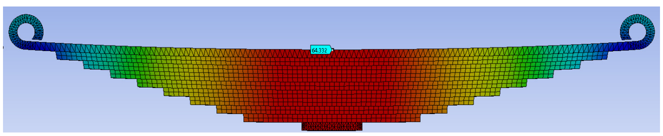

Fig. 11. The deflection for load case 2 (6.4 cm)

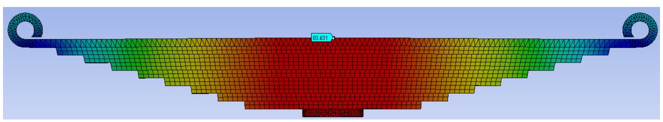

Fig. 12. The deflection for load case 3 (8.4 cm)

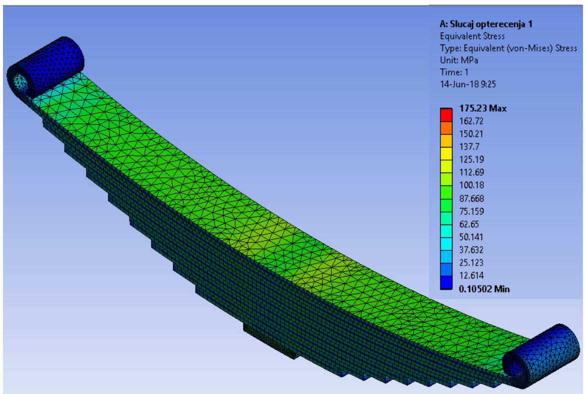

Fig. 13. The equivalent stress for load case 1

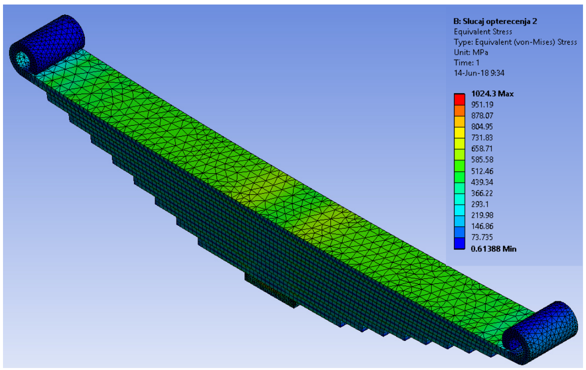

Fig. 14. The equivalent stress for load case 2

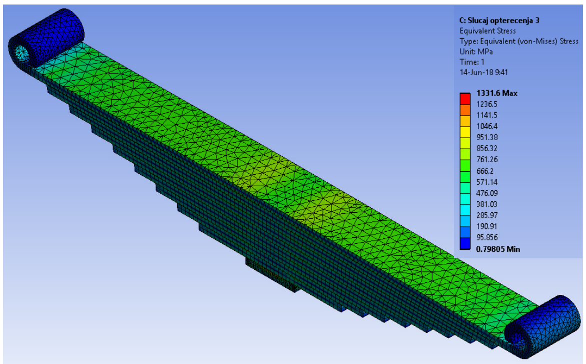

Fig. 15. The equivalent stress for load case 3

The obtained stress-strain state is more convenient to analyse over the static safety factor which is automatically obtained in Ansys. The static safety factor is defined by the ratio between yield strength and von Mises Stress (Fig. 16):

$$s_{st} = \frac{R_e}{\sigma_e} \geq 1 \tag{1}$$

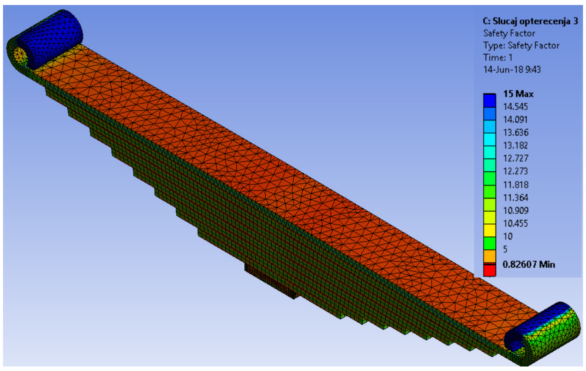

Fig. 16. The static safety factor for load case 3

Additionally, dynamic analysis of the considered leaf spring is performed. According to the Soderberg criterion, the dynamic safety factor is defined by the expression:

$$s_{din,sod} = \frac{R_e}{\sigma_{SR} + \sigma_a \cdot K_f \cdot \left(\frac{R_e}{\sigma_D} \right)} \qquad (2)$$

where: $\sigma_{SR}=(\sigma_{max}+\sigma_{min})/2$ – authoritative medium stress, $\sigma_a=(\sigma_{max}-\sigma_{min})/2$ – authoritative amplitude stress, $K_f=1$ – coefficient of stress concentration.

The dynamic calculation is performed for the case of uniaxial fatigue. It was adopted that the lower value of the load is 10% of the upper – maximum value. This is established on the basis of the results of the obtained equivalent stresses. So, the force varies from the load of the leaf spring for loaded wagon F_t, to maximum load F_{max}. Some of the obtained results of the lifetime and dynamic safety factor for the most critical load case are shown in Figs. 17 and 18.

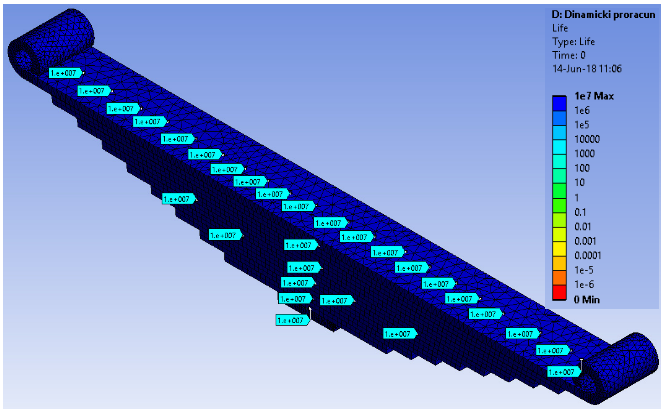

Fig. 17. The lifetime of the leaf spring

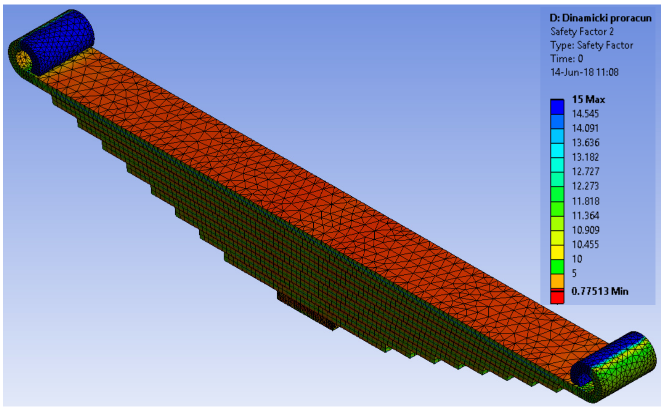

Fig. 18. The dynamic safety factor of the leaf spring

The obtained results have shown that the considered leaf spring is in the zone of permanent dynamic endurance, i.e. that it meets the necessary criteria from the aspect of dynamic strength.

In the final stage, the results obtained by the numerical calculation are compared with the results of analytical calculation (exposed in literature [5]). The comparative diagram of the deflection of considered leaf spring, obtained by the FEM and analytical way, is shown in Fig. 19.

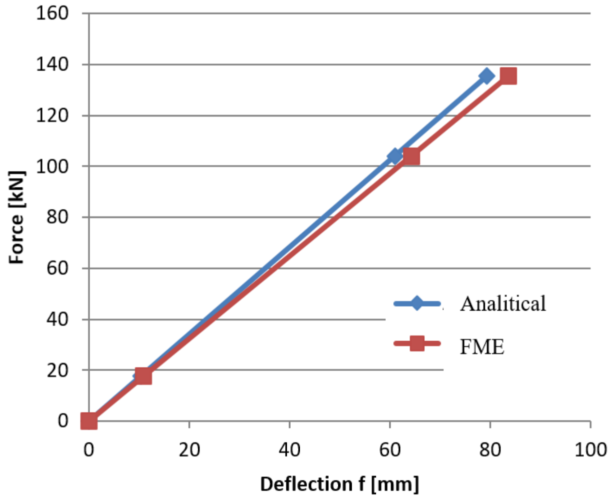

Fig. 19. The comparative diagram of leaf spring deflection obtained by the FEM and analytical way

6. CONCLUSION

This paper deals with the methodology of analysis of the leaf springs of the freight railway wagons by using modern software packages. In the example of considered leaf spring, deviations between numerical and analytical results are in the range of 5 %. This confirms validity of the proposed methodology of analytical calculation which can be applied in the design of various types of leaf springs in engineering practice.

ACKNOWLEDGEMENT

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RANDOM VIBRATION ANALYSIS OF THE RAILWAY OBSTACLE DETECTION SYSTEM DEMONSTRATOR HOUSING

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Abstract *–The paper presents random vibration analysis of the railway obstacle detection system (ODS) housing developed in the frame of S2R project SMART. In order to mount obstacle detection system demonstrator onto the vehicle, it was necessary to prove that the demonstrator housing satisfies the demands EN 61373:2010 standard for a Category 1 Class B device. The noted was performed by a numerical analysis of the obstacle detection system demonstrator, according to the demands of EN 61373:2010 standard. The analysis was performed by week coupling of static structural, modal and random vibration analysis. The random vibration analysis results were checked with fatigue analysis to assess the service life of ODS housing components for increased vibratory load. The results of the analysis show that the housing meets the requirements set by the railway EN 61373:2010 standard for a Category 1 Class B device.*

Keywords – Railway Obstacle Detection, Random Vibration Analysis, EN 61373:2010 standard

1. INTRODUCTION

Prototype solution for Obstacle Detection System (ODS) at mid-range (up to 200m) and long range (up to 1000m) was developed in the frame of project SMART (http://www.smartrail-automation-project.net) as a prerequisite for Autonomous Train Operation (ATO). A novel integrated multi-sensor on-board ODS for freight trains combines different vision technologies to identify obstacles up to 1000m. The obstacle detection system sensors are mounted into device housing for different evaluation tests in static and moving vehicles.

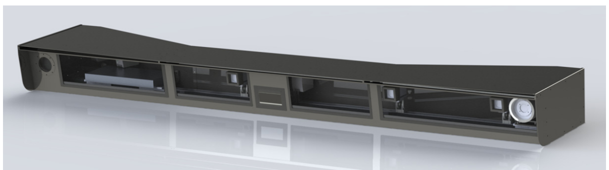

Fig.1. CAD model of the ODS housing

To obtain permits for evaluation it was necessary to prove that ODS demonstrator housing (Fig.1) is resistant to vibrations and it is designed to satisfy requirements by EN 61373:2010 – Rolling stock equipment – Shock and vibration tests for a Category 1 Class B device.

The simulation was performed as random vibration simulation in ANSYS Workbench 19.2 [2] software according to the demands of EN 61373:2010 as well as by the same procedures defined by standard. According to the noted standard, the housing must sustain increased vibratory loads which simulate service conditions for a period of 5 hours which correspond to normal service life of vehicle (25 years) [3].

For a Category 1 Class B device Table 1 defines the Acceleration Spectral Density (ASD) values, while Figure 2 defines frequency range which should be used during testing.

To complete above mentioned random vibration analysis, it is necessary to preform four linked analysis in ANSYS software. The first analysis is used to determine stress-strain state of the housing during normal service load and its deformed shape when subjected to service loads. In the second step, the modal analysis is performed for a deformed shape (under service loads) of ODS housing in order to determine primary natural frequencies. In the third

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step a random vibration analysis is performed to determine the stress-strain state under increased vibratory load and finally a fatigue analysis is performed in order to assess the service life of ODS housing components for increased vibratory load.

Tab. 1. ASD and RMS values for simulated long life testing at increased vibration levels for a Category 1 Class B device [4]

	Vertical	Transverse	Longitudinal
Long life ASD level $(m/s^2)^2/Hz$	6.12	4.62	1.32
RMS value 2 to 250 Hz	30.6	26.6	14.2

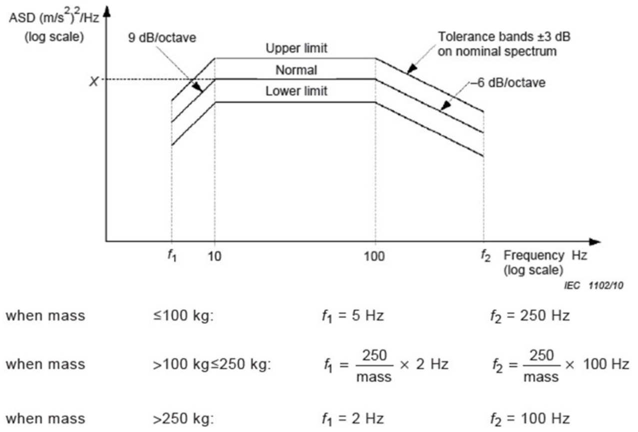


Fig.2. Frequency range for simulated long life testing at increased vibration levels for a Category 1 Class B device [3]

2. RANDOM VIBRATION ANALYSIS

To perform all above mentioned analyses firs it was necessary to prepare the FEM model. In order to prepare the noted FEM model internal components and sensors were removed from the geometrical model as they were not a subject of analysis. According to the standard EN 61373 the internal components of the housing mounted on a vehicle body are not tested as they cannot fall of the vehicle as they are already located in protective case (housing). The ballasts used to increase the mass for vibration isolation purposes were added to the model of the housing.

The reduced geometric model of the redesigned housing was transformed into the discretized Finite Element Model FEM with the application of advanced meshing tools. The discretized model consisted of 2661038 nodes, forming 510620 finite elements.

Connection between ODS housing parts were taken as bonded as they are joined by bolted connections or by welding which corresponds to noted contact condition. The contact stiffness was updated in every simulation iteration and the contacts were defined by a pure penalty method. All contacts were treated as asymmetric to avoid errors in calculation of contact parameters.

The materials were assigned to the model components according to the design documentation. In total four materials were used:

- steel S355J2GR for all housing elements made as sheet metal components and stiffening profiles,
- aluminium for a sensor rail
- tempered glass for transparent protective windows
- germanium glass for thermal camera protective window.

Material properties were taken from GRANTA material database which is a part of ANSYS 19.2 software [2]. Stress-strain properties of material S355J2G3 were defined with isotropic bilinear hardening in order to more accurately obtain stress state of reliefs (which are characteristic to sheet metal parts) as stress concentrations due to analysis singularity are expected in noted areas.

Figure 3 show the deformed shape of the ODS housing in static structural analysis. The maximal deformation is approximately 0.3 mm which is well below the critical limit.

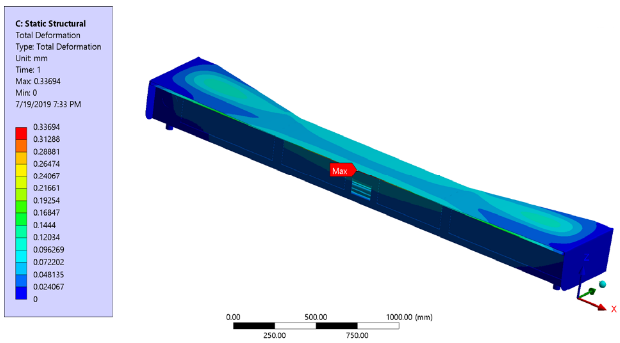


Fig.3. Deformed state of ODS housing

Figure 4 shows the equivalent stress in static structural analysis. The maximal stress is approximately 37MPa which is well below allowable stress for steel S355 J2G3 (355 MPa).

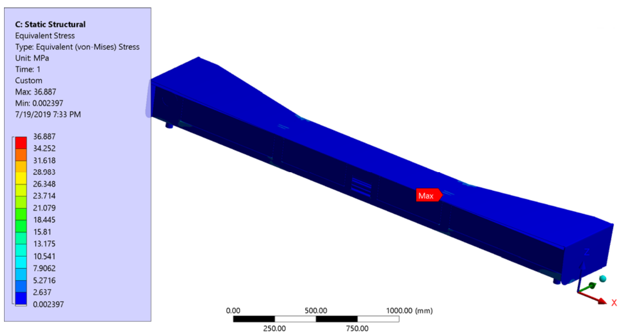


Fig.4. Equivalent stress of ODS housing

Based on preformed static structural analysis it can be concluded that the housing has a satisfactory stiffness and that when subjected to loads, stress and deformations are significantly below the allowable ones.

The second step was to perform a modal analysis of the deformed shape of ODS housing. The modal analysis was performed in range between 0 and 200 Hz. Figure 5 show the natural frequencies of the redesigned ODS housing.

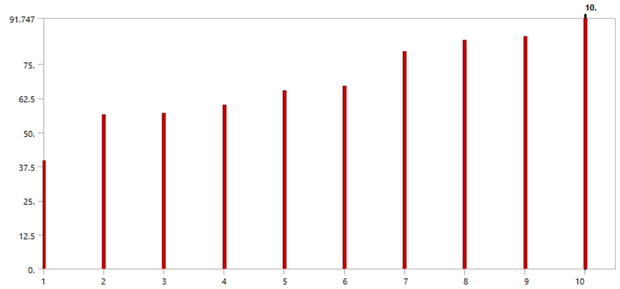
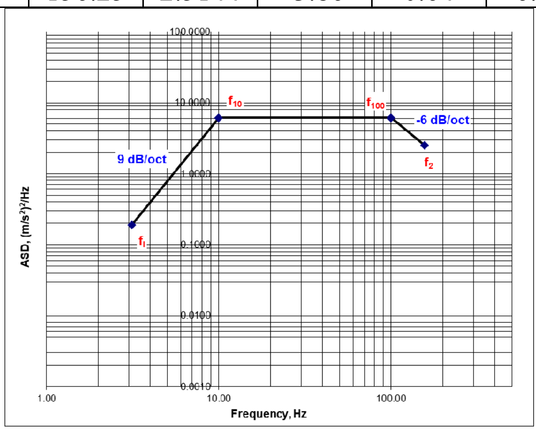


Fig.5. The ODS redesigned housing natural frequencies determined by modal analysis in the loaded state

The modal results were transferred to random vibration analysis. The random vibration analysis was performed by exciting the fixed supports defined in static structural analysis with vibration load in vertical, transverse and longitudinal directions as defined in Table 1. For a housing mass of 160 kg with ballasts installed, the limiting frequency were calculated and ASD curves were formed for all three loading directions as shown in Tables 2-4.

Tab. 2. ASD load at base excitation in vertical direction

Frequency, Hz		ASD, $(m/s^2)^2/Hz$	dB	OCT	dB/OCT (Slope)
f_1	3.13	0.1889	*	*	*
f_{10}	10.00	6.1200	15.11	1.68	9.00
f_{100}	100.00	6.1200	0.00	3.32	0.00
f_2	156.25	2.5144	-3.86	0.64	-6.00

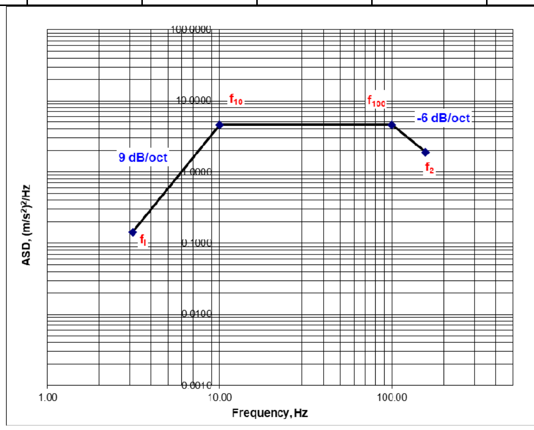


Figures 6-8 show the 1σ, 2σ and 3σ equivalent stress results obtained by postprocessing the random vibration analysis results.

From noted figures for almost all parts of the ODS housing the probabilistic stresses are below allowable ones for materials used in analysis. The very high stresses values occur due to singularity at sharp corner of relief at back side sheet metal part (Fig. 9).

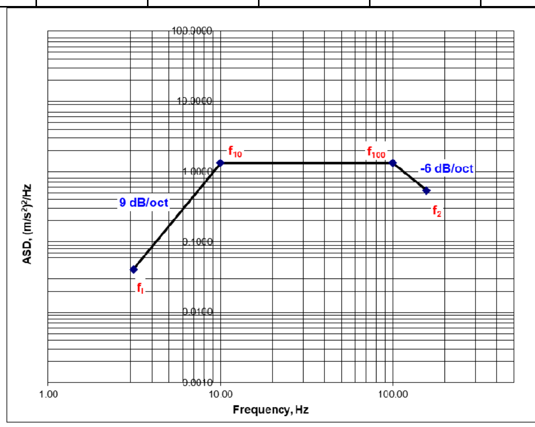
Tab. 3. ASD load at base excitation in transverse direction

Frequency, Hz		ASD, $(m/s^2)^2/Hz$	dB	OCT	dB/OCT (Slope)
f_1	3.13	0.1425	*	*	*
f_{10}	10.00	4.62	15.11	1.68	9.00
f_{100}	100.00	4.62	0.00	3.32	0.00
f_2	156.25	1.8969	-3.87	0.64	-6.00



Tab. 4. ASD load at base excitation in longitudinal direction

Frequency, Hz		ASD, $(m/s^2)^2/Hz$	dB	OCT	dB/OCT (Slope)
f_1	3.13	0.0408	*	*	*
f_{10}	10.00	1.3200	15.10	1.68	9.00
f_{100}	100.00	1.3200	0.00	3.32	0.00
f_2	156.25	0.5425	-3.86	0.64	-6.00



As this is a consequence of numerical problem at noted spot they can be neglected. Even if high stress values at single point occur, material will yield and plastically deform thus scientifically lowering the stress levels.

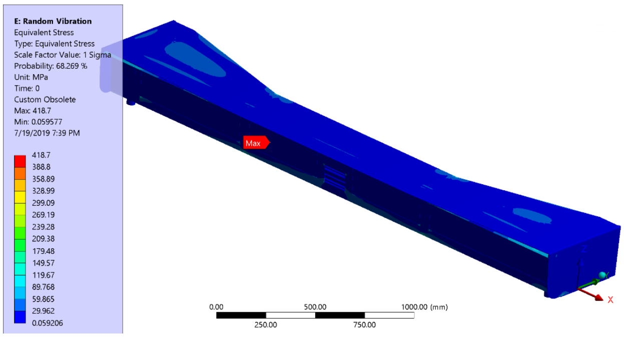


Fig.6. 1σ equivalent stress of ODS housing

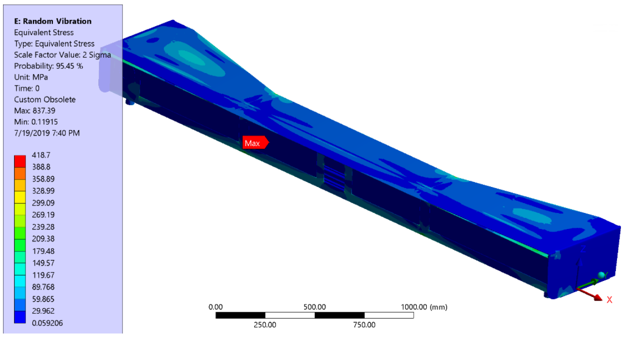


Fig.7. 2σ equivalent stress of ODS housing

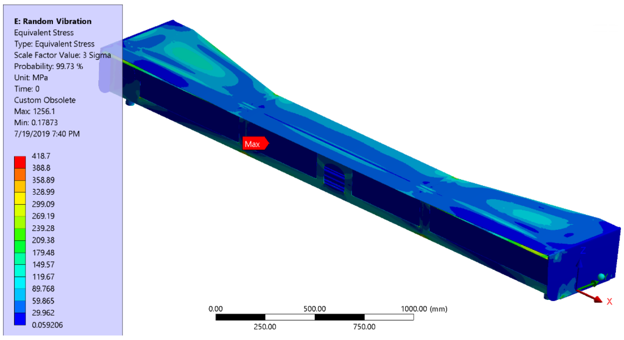


Fig.8. 3σ equivalent stress of ODS housing

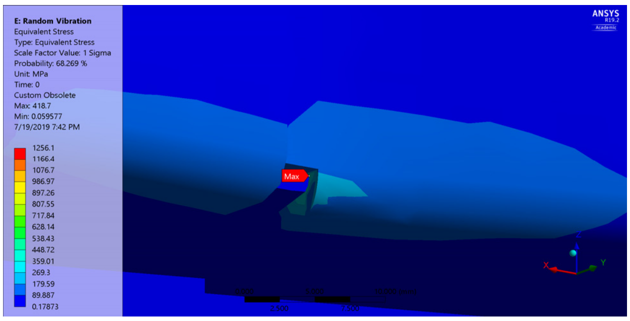


Fig.9. 1σ equivalent stress of back side of ODS housing

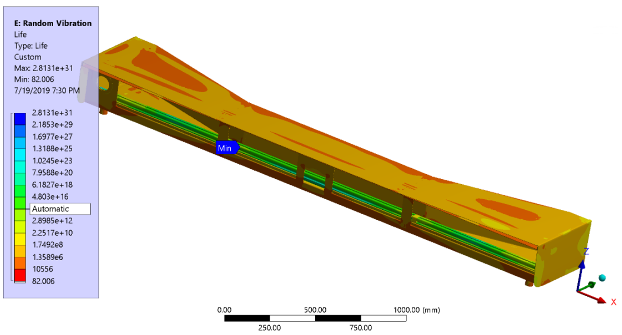


Fig.10. Random vibration fatigue life

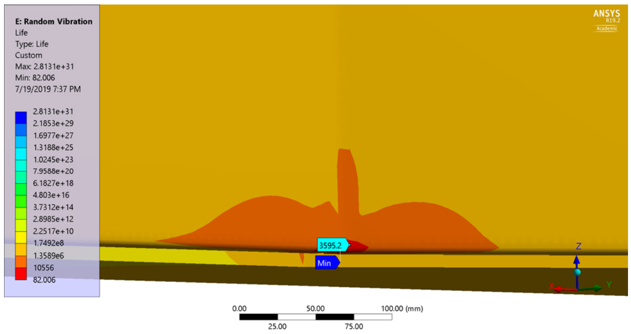


Fig.11. Random vibration fatigue life at back side of ODS housing

Based on obtained probabilistic stress results a fatigue analysis was performed in the last step based on S-N curves defined in GRANTA material database for materials used in analysis.

Results of fatigue life analysis are shown on Figure 10. Expected life during testing at increased vibration levels is well above 5h which correspond to expected vehicle service life of 25 years. The singularity occurrence at relief of back side sheet metal part resulted in lower life expectancy but noted results can be neglected as it is well known that stresses due to singularity tend to infinity (known limitation of Finite Element Method). Even if noted results are taken as realistic, the life expectancy in noted area is larger than 3000 h which correspond to 4.2 years in service (Fig.11). As ODS demonstrator will not be mounted for more than several days on a vehicle, noted life expectancy is more than sufficient.

3. CONCLUSION

Based on above preformed analysis it can be concluded that design of ODS housing satisfies the requirements imposed by EN 61373:2010 for a Category 1 Class B device. Results of the above performed analysis were submitted to owner of the vehicle, who accepted it as a proof that designed housing will not disassemble or fall od from the vehicle body during evaluation.

ACKNOWLEDGEMENT

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XIX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS RAILCON '20

METHOD FOR THEORETICAL DETERMINATION OF THE CRITERION AGAINST DERAILMENT BASED ON EXPERIMENT

Dobrinka ATMADZHOVA[1]

Abstract *– Despite the existence of many examinations and developments so far, the mechanism of flange climbing onto rail heads is still unclear due to the extreme complexity of interaction in the wheel-rail system. Through analysis and reflection on the Nadal criterion and the balance of the forces acting at the contact point, two boundary states and three characteristic zones are identified - safety, friction and derailment. Based on Nadal dependency, by decomposition, separation and structural analysis of the forces valid for derailment, the criterion is transformed in the nominal criterion against derailment taking into account the "frame-wheelset" force. The paper defines a new system (called virtual) with 2 wheels (attacking and non-attacking) and the action of horizontal and vertical forces. These forces, which are in fact acting and containing the additives of frame force, are reported at the wheel-rail contact points. The influence of wheel load unevenness on the boundary value of criterion against derailment is also taken into account. The introduction of this new diagnostic parameter in the system facilitates its improvement in terms of identifying ability, sensitivity and driveability.*

Keywords – Railway vehicles, criteria against derailment, derailment, security factor against derailment.

1. INTRODUCTION

Traffic safety is one of the main topics in research on rolling stock dynamics. Accidents in the railway transport caused by rolling stock derailment constitute the highest part of all railway accidents.

Under Directive 2004/49/EC [1] each EU member state shall ensure that it provides railway safety and increase of its level in compliance with the development of Community legislation and scientific and technical progress. For this purpose, European Railway Agency (ERA) was established [2]. A number of methods and sensory systems have been developed to measure the forces of wheel-rail interaction under operational conditions [3-8].

The international regulations (standards) for testing used to assess the dynamic behaviour of railway vehicles – UIC code 518 [9] and EN 14363 [10] define a set of test conditions, describe the data processing rules and give the limit values of specified quantities of assessment.

The regulations mentioned above state that the so-called normal method is based on the measurement of the contact forces Y (horizontal-transverse) and Q (vertical) of wheel/rail contact indicating the following evaluation parameters:

- ΣY, the total force exercised laterally on the track by wheel axles;
- Y/Q ratio used to assess the risk of derailment by flange climbing onto rail head;
- Yqst, the mean value of the lateral distortion force exercised on the outer rail in curves;
- Q, the maximum vertical force exercised on the outer rail in curves;
- Qqst, the mean value of vertical force exercised on the outer rail in curves.

The first two forces (ΣY and Y/Q) are considered important for safety while the others are used to assess the track fatigue.

In addition, the lateral accelerations are measured on the bogie frame (above the wheel axles) and the lateral and vertical accelerations are measured in the body (above the central bearings). The body accelerations are used in the normal method for evaluating the "running behaviour".

The CR-RST-Freight Wagon TSI section 4.2.3.4.2.1 requires new or upgraded wagons to comply with a maximum Y/Q of 1.2 for curves less than 250 m radius and with a maximum Y/Q of 0.8 for curves equal or greater than 250m radius.

The TSI links the two Y/Q limits to differing curve radii, however normally they are linked to vehicle speed and input conditions, as they relate to differing vehicle behaviour [11].

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2. ANALYSIS ON THE NADAL'S CRITERION AND THE BALANCE OF THE FORCES ACTING AT THE CONTACT POINT "WHEEL-RAIL"

Nadal derailment criterion determines the maximum (limited) value of ratio between lateral force Y and vertical force Q acting on the wheel at the point of wheel-rail contact.

$$(Y_1 / Q_1)_{lim} = (tg\gamma_1 - \mu)/(1 + \mu tg\gamma_1) \qquad (1)$$

Analyzing the derailment process, we notice that Nadal's formula is inferred only from the contact forces on the attacking wheel, without taking into account neither the dependence that is between the load on the wheel and the guidance force nor the influence of the spin effect in the contact point on the flange of the wheel over the friction factor [12].

3. STUDY ON THEORETICAL FUNDAMENTALS OF CRITERIA AGAINST ROLLING STOCK DERAILMENT

Through analysis and reflection on the Nadal criterion and the balance of the forces acting at the contact point, two boundary states and three characteristic zones are identified - safety, friction and derailment. Based on Nadal dependency, by decomposition, separation and structural analysis of the forces valid for derailment, the criterion is transformed in the criterion against derailment taking into account the "frame-wheelset" force.

As an initial (given) real criterion that should be adaptated to ratio Y/Q approved internationally according to EN 14363 and UIC 518, the so-called "nominal" criterion Y_p/Q'_1 with participation of horizontal nominal force Y_p called "frame" or "axial" transmitted between the axle and frame is introduced [13]; as well as vertical force Q'_1 representing the resultant force at the contact point of attacking wheel.

The computational scheme of the task is given in Fig. 1 where the attacking wheel 1 contacts the rail edge rounded by the flange with point A_1 in the conical zone (or if there is not such one, in the inflection zone) where the slope angle γ_1 to the horizontal has a maximum value and the non-attacking wheel contacts point A_2 of the rolling surface to the upper surface of the rail head - γ_2. Vertical forces P_1 and P_2 transmitted from the structure are applied to the axle necks of wheels 1 and 2 respectively, and force P_0 of the wheel axle own weight is applied to its centre; horizontal force Y_p transmitted by the structure to the wheel axle known as "frame force" is applied at a distance h in vertical direction from the horizontal plane of rail heads, whereby this distance is assumed to be not only equal, but also less or greater than the radii of wheels. Reactive forces N_1 and N_2 at contact points A_1 and A_2 respectively follow the directions of respective normals n_1 and n_2 to the supporting surfaces and friction forces $\mu_1 N_1$ и $\mu_2 N_2$ have the same directions as respective tangents t_1 and t_2 and opposite directions of the preset displacements.

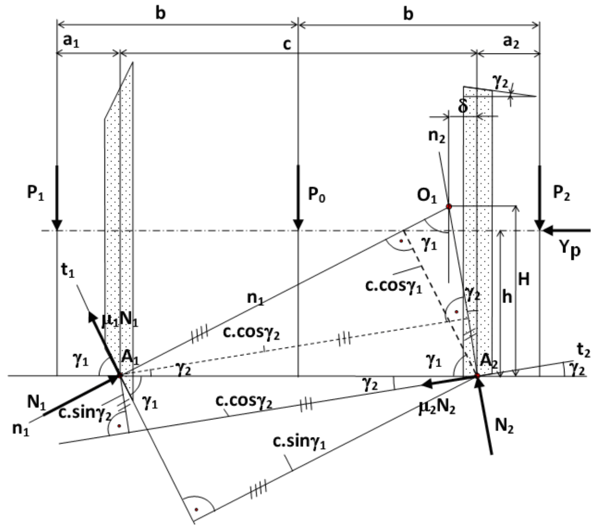

Fig.1. Computational scheme for determining the so-called "Nominal" criterion against derailment

To determine the nominal criterion we get the equation:

$$\frac{Y_P}{Q'_1} = \frac{1 - A - \dfrac{Q'_2}{Q'_1}\left[\dfrac{\delta / c}{1 - \delta / c} + B\right]}{cot\, g\gamma_1 - \dfrac{h / c}{1 - \delta / c} + A.h / c - B.h / c} \qquad (2)$$

$$A = \frac{\mu_1}{sin\,\gamma_1 (cos\,\gamma_1 + \mu_1\, sin\,\gamma_1)}, \quad B = \frac{\mu_2}{tg\gamma_1.(cos\,\gamma_2 - \mu_2\, sin\,\gamma_2)}$$

and $\delta = c.tg\gamma_2 /(tg\gamma_1 + tg\gamma_2)$

where: γ_1 and μ_1 – the angle of flange and friction coefficient at the flange-rail contact point of attacking wheel respectively; μ_2 – friction coefficient at the flange-rail contact point of non-attacking wheel; Q'_2 and Q'_1 – vertical load on both wheels of a wheel-axle and h/c – parameter taking into account the geometry location of nominal force Y_p; δ - horizontal deviation of the center of rotation item O_1 from the vertical through the contact point A_2.

The influence of wheel load unevenness on the boundary value of criterion against derailment is also taken into account through the parameter Q'_2/Q'_1. Apart from its substantial influence on the final result and adequacy of safety against derailment assessment, the newly introduced additional member has important significance. Due to that, this member is inextricably linked to the main part of formula and successfully used in compiling linear graphs of force functions, nomograms and analytical dependencies in regard to methodological compatibility between different criteria. The introduction of this new diagnostic parameter in the system facilitates its improvement in terms of identifying ability, sensitivity and drive ability.

4. EXPERIMENTAL DETERMINATION OF THE SAFETY CRITERION AGAINST DERAILMENT

The determination of Y/Q criterion validated by the Euro-norms and UIC criterion is possible only experimentally, at that with the help of a special force-measuring wheel axle with appropriate equipment and staff provided by the owner to be used under certain conditions; or giving tests to be completely performed by West European companies, which is even more disadvantageous for Bulgaria. This state inevitably generates an alternative to seek another solution at least for the most common cases of low responsibility – for example, according to the objective set here – the theoretical determination of criterion against derailment Y_1/Q_1 and Y/Q respectively, by no direct method but indirectly as follows: by theoretical or experimental determination of the nominal criterion against derailment Y_p/Q'_1 and its subsequent adaptation to conditional criterion Y_1/Q_1, which is considered equivalent to criterion Y/Q established in compliance with EN and UIC. As for the actual adaptation from Y_p/Q'_1 to Y_1/Q_1, it is based on the disclosed methodological compatibility and the transformational dependencies between criteria Y_p/Q'_1 and Y_1/Q_1:

$$\frac{Y_1}{Q_1} = \frac{Y_p / Q'_1}{1 + Y_p / Q'_1 . h / c}\left[1 - \mu_2 . \frac{h}{c}\left(1 + \frac{Q'_2}{Q'_1}\right)\right] \qquad (3)$$

which is valid for $Q'_2/Q'_1 > 0$, and $Q'_2/Q'_1 = 0$.

For the safety factor against derailment η we get the dependence:

$$\eta = \frac{\dfrac{Y_p / Q'_1}{1 + h/c . Y_p / Q'_1} . \left(\dfrac{h}{c}\right)^2 . \dfrac{1}{\mu_2}}{\dfrac{Y_1}{Q_1} - \dfrac{Y_p / Q'_1}{1 + h/c . Y_p / Q'_1}\left[1 - \mu_2 . \dfrac{h}{c} - \dfrac{1}{\mu_2} . \left(\dfrac{h}{c}\right)^2\right]} \qquad (4)$$

Figure 2 shows a diagram of Y_p/Q'_1 - nominal criterion against derailment, depending on the approved criterion Y/Q according to EN and UIC, at different values of the parameters Q'_2/Q'_1, μ_1 and γ_1.

Using the method of the smallest quadrants, the dependences of trend lines are obtained on which the measured results of the operation of Y_1/Q_1 or Y_p/Q'_1 can be mutually transformed.

Measurements of the anti-derailment criteria Y_p/Q'_1 and Y_1/Q_1 were performed for a passenger car type B-84 with a bogie type T73-AD [14], at $\mu_1 = 0.36$ for different parameters Q_2/Q_1 and γ_1. The results of the measurements and the calculated values of Y_1/Q_1 according to formula (3) are given in Table 1.

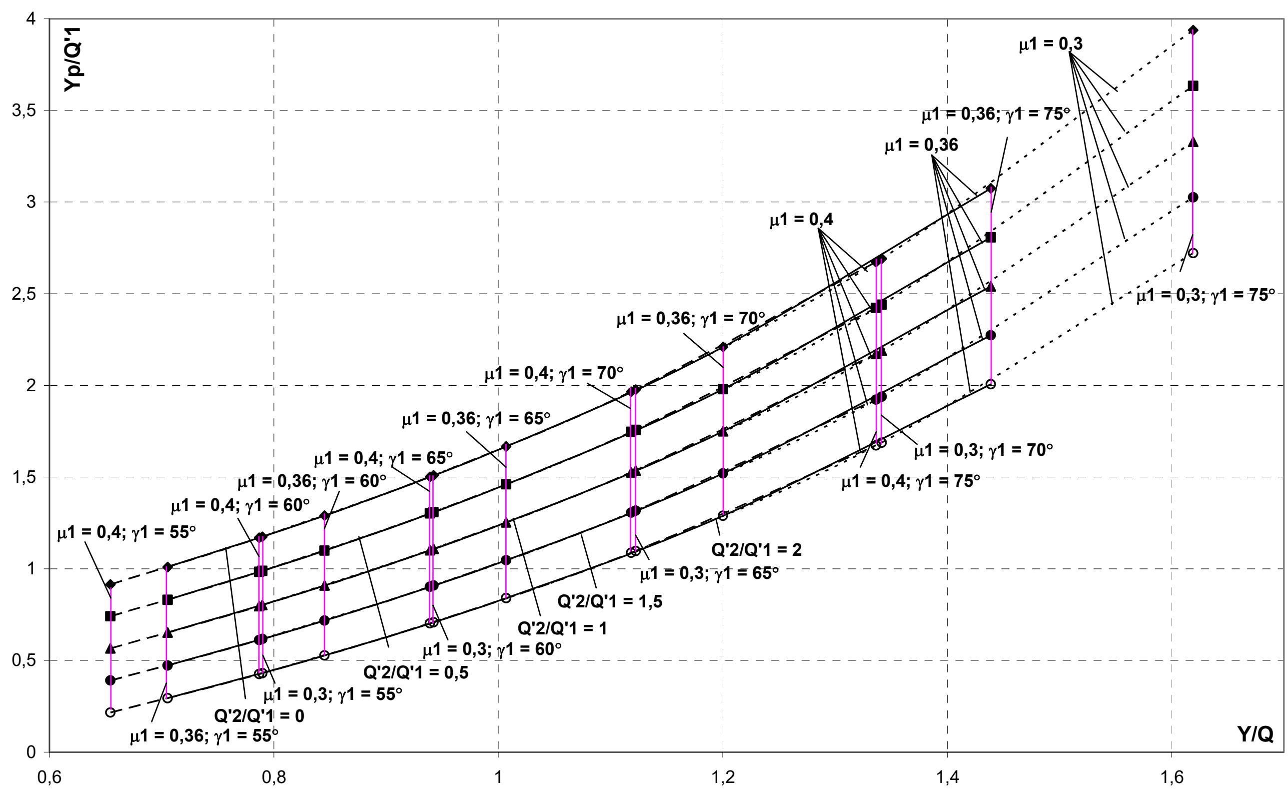

Fig.2 Diagram of Y_p/Q'_1 - nominal criterion against derailment depending on the approved criterion Y/Q according to EN and UIC, at different values of the parameters Q'_2/Q'_1, μ_1 and γ_1.

Table 1. Measurement results of the anti-derailment criteria Y_p/Q'_1 and Y_1/Q_1 for a passenger car type B-84 with a bogie type T73-AD

Yp/Q'1 measured				
Q_2/Q_1 =	0	0,5	1	1,5
γ_1 = 65°	1,667	1,460	1,253	1,046
γ_1 = 70°	2,210	1,980	1,750	1,519
γ_1 = 75°	3,074	2,807	2,540	2,273
Y_1/Q_1 measured				
γ_1 = 65°	1,007	0,882	0,757	0,632
γ_1 = 70°	1,200	1,075	0,950	0,825
γ_1 = 75°	1,439	1,314	1,189	1,064
Y_1/Q_1 calculated				
γ_1 = 65°	1,019	0,892	0,766	0,639
γ_1 = 70°	1,222	1,095	0,967	0,840
γ_1 = 75°	1,476	1,348	1,219	1,091

The relative errors from the measurements and calculations are 1.15 - 2.56%. These results show good convergence between measurements and calculations.

5. CONCLUSION

Paper gives an overview and evaluation of the existing examinations on theoretical fundamentals and promising special trends of safety against derailment in railway transport. The experience, research and contributions and inconsistencies of different developments are presented.

The publication is defined and creates new system with 2 wheels (attacking and non-attacking) and the action of horizontal and vertical forces Y and Q respectively. These forces, which are in fact acting and containing the additives of frame force Yp are reported at the wheel-rail contact points. The influence of wheel load unevenness on the boundary value of criterion against derailment is also taken into account. Apart from its substantial influence on the final result and adequacy of safety against derailment assessment, the newly introduced additional member (with parameter Q_2/Q_1) has important significance. The introduction of this new diagnostic parameter in the system facilitates its improvement in terms of identifying ability, sensitivity and driveability.

Results of measurements of the anti-derailment criteria Y_p/Q'_1 and Y_1/Q_1 for passenger wagon type B-84 with bogie type T73-AD are presented, at $\mu_1 = 0.36$ the results of which show good convergence between measurements and calculations.

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XIX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
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ASSESSING THE IMPACT OF THE LATERAL SWINGING OF THE TRAM TO ITS ELECTRICAL CURRENT COLLECTOR

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Emil IONTCHEV[2]
Rosen MILETIEV[3]
Boris PETKOV[4]

Abstract *– This article presents a study aimed at assessing the impact of the side to side swinging of the body of the tram over the electrical current collector, caused by the dip in the railroad and to research the reasons behind the failures of it. The rail track on which the research took place is made of grooved rails on top of panels. Due to the usage of the track, there are frequent asymmetrical collapses of the two rails which have different frequency and depth. The needed data for determining the side to side swinging of the body has been obtained with an inertial measuring system, which has been mounted on the roof of the carriage just under the electrical current collector. The values of acceleration, angular velocities and magnetic field in the three axes of the tram have been obtained from it. It has been found that the lateral swinging of the tram body causes high dynamic loads in the structure of the collector and this leads to damages and accidents.*

Keywords – tram, electrical current collector, railroad, accelerometer, gyroscope, magnetometer, Kalman filter.

1. INTRODUCTION

The current collectors are designed to be resistant to longitudinal and vertical forces during movement, ie. loads from accelerations when starting and stopping and from the pressure on the contact wire.

This gives the structure security at significantly lower loads in the transverse direction.

2. STATUS OF THE PROBLEM

In recent years, there has been an increase in the number of faults to the current collectors of tramways in the city of Sofia. The predominant damages are: appearance and development of cracks on the elements of the current collector, damages on the hinges, deformations of the thinner elements in the upper part, damages on the connecting elements and the mechanisms of the stand of the sliders. These faults are typical for the trams moving primarily on routes, which in some parts have sections with rail track in poor condition.

The tramways in the city of Sofia are equipped with different types and models of current collectors. Symmetrical are: Pf-80, KE28. Asymmetrical are: Fb500.54, Fb700.87 и ESgs 17-3100. Depending on their construction they have different faults.

3. MEASUREMENTS

Measurements were carried out along the route from The Triangle junction to the Iliyantsi turning ear. The route is built with stemless grooved rails on top of panels. Due to the long-term operation, there are frequent asymmetrical collapses of the two rails with different frequency and depth.

The sensors were placed in trams type T8M 700 M with inventory № 923 and type T6A2-BG with inventory № 3014. The measurements were made in operational mode with passengers.

4. PROCESSING OF THE DATA

An inertial measuring system was used to determine the angles at which the tram tilted during its movement relative to the local north-east-down

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coordinate system. In it are included triaxials: accelerometer, gyroscope and magnetometer. They are mounted on a single base, ensuring alignment between their axes. The system is fixed to the ceiling of the tram in the area where the pantograph is located, as shown in figure 1.

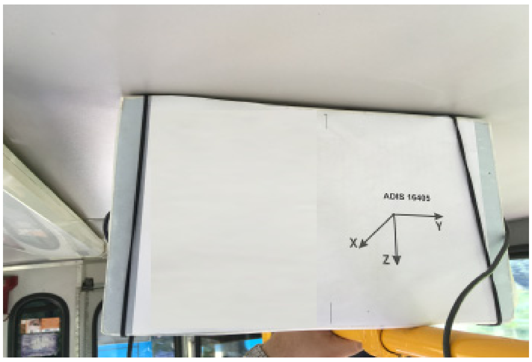

Fig.1. Inertial measuring system

The orientation of the axes of the sensors and the angles that describe the spatial position of the tram are shown in Figure 2.

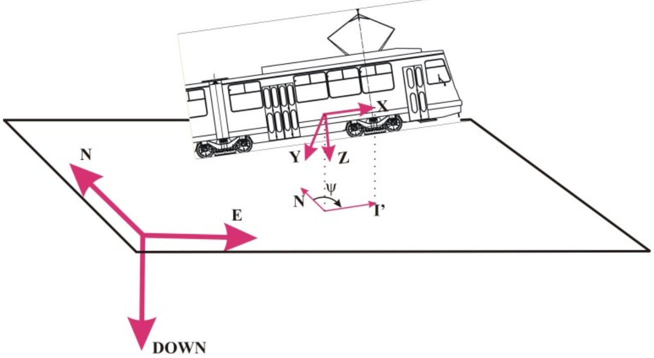

Fig.2. Orientation of the tram axes and the local coordinate system

The relationship between the coordinates of the sensors in the two systems is given by the expression (1)[1]:

$$V^{local} = \left(R_{local}^{body}\right)^{T} . V^{body} \qquad (1)$$

In order to calculate the matrix R_{local}^{body}, it is necessary to determine the Euler angles Φ, Θ, ψ. The sequence of rotation around the axes, when converting coordinates, from the coordinate system of the tram to the local coordinate system, is shown in Figure 3.

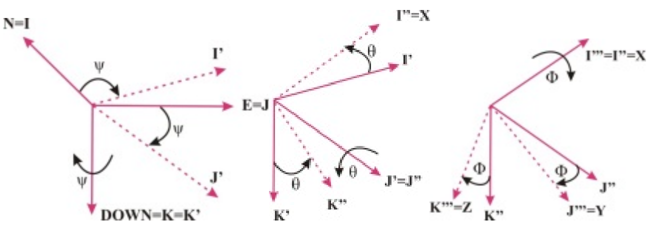

Fig. 3. Sequence of rotation of the axes

The data from the various sensors were processed using an algorithm in which a Kalman filter was used to obtain the required angles [2]. The way the data from the different sensors are combined is shown in Figure 4.

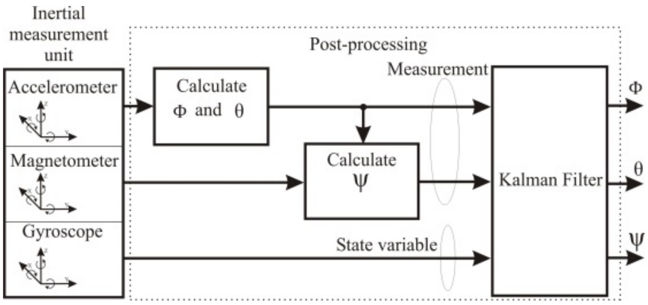

Fig.4. Calculation of the angles

5. RESULTS.

To determine the influence of the rocking of the body of the tram on the pantograph, the following parameters are taken into account: the accelerations along the transverse axis $\vec{a}_y$, the angular speed of rotation relative to the longitudinal axis ω_x and the angle of inclination of the body of the tram in the transverse plane Φ_x.

For the tram with inventory № 923 the measured maximum values of the parameters are:

$\vec{a}_{y\max,923} = 1,7\ m.s^{-2}$; $\omega_{x\max,923} = 3,5\ \deg.\sec^{-1}$, $\sphericalangle\Phi_{x\max,923} = 15\ \deg$.

For the tram with inventory № 3014 the measured maximum values of the parameters are:

$\vec{a}_{y\max,3014} = 0,95\ m.s^{-2}$; $\omega_{x\max,3014} = 3,0\ \deg.\sec^{-1}$, $\sphericalangle\Phi_{x\max,3014} = 7\ \deg$.

It is noteworthy that the values for the tram with inventory № 923 are higher. This is due to the type of suspension of the chassis. The tramways type T8M 700 M have a two-stage spring suspension made of sets of cylindrical coil springs. While trams type T6A2-BG have a fixed guide of the axles and cylindrical coil springs in the central spring.

6. INFLUENCE ON THE CURRENT COLLECTOR

The design of the current collectors (Figure 5.a) is a mechanism designed to work in one plane [3]. This is a plane defined by the X and Z axes. While in the transverse plane it can be considered as a singe body (Figure 5.b).

When shaking the basket, the entire current collector has the same deviation. This leads to a load in the hinge joints of the structure. The loads are different according to the type of construction, at what height they are and what masses are above them.

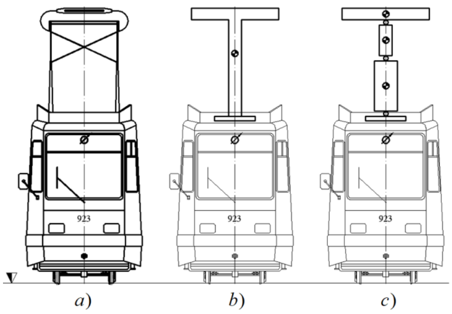

Fig.5. Schemes of the current collector as one body and as a composite body

Due to their immobility in the transverse direction, hinged connections are considered to be thinner places in the structure (Figure 5.c).

The pantograph can be divided into four levels:

- base – firmly attached to the roof of the basket by insulating elements;
- lower level – the elements below the middle hinges;
- upper level – the elements above the middle hinges;
- head – stand of sliders with sliders.

For each of the levels, no matter how many elements it consists of, we assume that its mass m_i is concentrated in the center of gravity. The same goes for the hinges - regardless of their number, they are considered one. These points of the structure are chosen as characteristic and the calculations for the loads are made in regards to them. The points of the center of gravity of each of the bodies of the pantograph are marked with B_i, the centers of the hinges – with S_i. The point where the sensor is located is marked with C.

Figure 6 shows the pantograph as a single body.

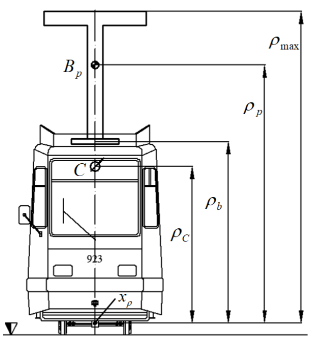

Fig.6. Location of the characteristic points in case the current collector is considered as one body

Figure 7 shows the pantograph as a component body. Its levels are separated into separate bodies.

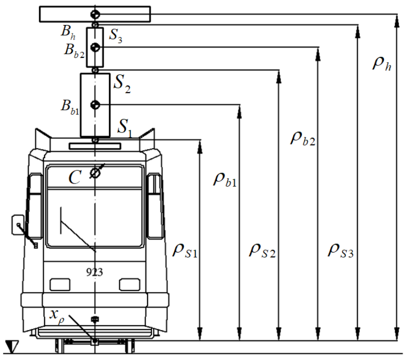

Fig.7. Location of the characteristic points in case the current collector is considered as a composite body

It is assumed that the rocking of the basket is a partial rotation around an axis x_ρ parallel to the longitudinal axis of the basket – X, at a height around the axes of the wheelset, depending on the design of the spring suspension. From the measurements made, the values of the angular velocity ω_x when rotating around the axis x_ρ, the angle of rotation - Φ_x and the accelerations along the Y axis - $\vec{a}_y$ were obtained. The distance from the axis x_ρ to each of the characteristic points is ρ_i, and to the sensor ρ_C.

The angular velocity ω_x and angular acceleration ε_x, which are derivatives of the angle of inclination of the body Φ_x, are the same for all points of the pantograph. The measured effective values of the acceleration due to the small angle of deviation can be considered as values of the tangential acceleration.

The following dependences are used to calculate the loads at the accepted characteristic points of the current collector [4]:

- for the angular acceleration: $\varepsilon_x = \dfrac{\vec{a}_y}{\rho_C}$;
- for the tangential acceleration at the characteristic points: $\vec{a}_\tau = \varepsilon_x.\rho_i$;
- for the force at the center of gravity of each of the levels: $F_i = m_i.\vec{a}_\tau$;
- for the bending moment in the hinges: $M_i = F_i.\rho_i$;
- for the linear velocity at the characteristic points: $v_i = \omega_x.\rho_i$.

If we consider the scheme, which accepts the current collector as one body (Figure 6.), then the entire load from the swing is taken by the connection between the base and the roof of the tram. After replacement and conversion for the bending moment in the base of the pantograph is obtained:

$$M_b = m_p.\varepsilon_x.\rho_p.\left(\rho_p - \rho_b\right) \quad (2)$$

When considering the scheme, which accepts the current collector as a composite body of its levels (Figure 7.) for the bending moment in the hinged connections connecting the levels after replacement and conversion, separate dependences are derived.

For the hinges connecting the pantograph head to the upper stage:

$$M_{S3} = m_h.\varepsilon_x.\rho_h\left(\rho_h - \rho_{S3}\right) \quad (3)$$

For the middle hinges the parameters are in accordance with the specific construction and the bending moment is calculated by:

$$M_{S2} = \left(m_h + m_{b2}\right).\varepsilon_x.\rho_{(h+b2)}.\left(\rho_{(h+b2)} - \rho_{S2}\right) \quad (4)$$

where: $\left(m_h + m_{b2}\right)$ - the sum of the masses of the head and the upper level; $\rho_{(h+b2)}$ - distance of the center of gravity of the masses above the middle hinge to the axis of rotation of the body.

For the main hinges, the parameters are taken into account with the specific construction and the bending moment is calculated by:

$$M_{S1} = \left(m_h + m_{b2} + m_{b1}\right).\varepsilon_x. \\ .\rho_{(h+b2+b1)}.\left(\rho_{(h+b2+b1)} - \rho_{S1}\right) \quad (5)$$

where: $\left(m_h + m_{b2} + m_{b1}\right)$ - the sum of the masses above the main hinge; $\rho_{(h+b2+b1)}$ - distance of the center of gravity of the masses above the main hinge to the axis of rotation of the body.

The details and assemblies of railway vehicles are mostly endangered by tired destruction, which occurs years after the production and commissioning of large batches and series, usually of a mass nature, and is associated with huge material damage [5, 6, 7].

Fatigue strength is affected by two groups of loads - resistances and loads. The current collectors are subjected to loads of constant and random nature. The constant loads are from the static load and have relatively low values. The dynamic loads from the road have significantly higher values and reach the zone of plastic deformations of the material [7].

From the described experiment, information can be derived about the behavior of the pantograph and the accelerations of its elements when passing through the collapse of one rail.

The results show that the dynamic load is random and depends on the condition of the track. When driving on a route with poor road condition, at some points the stresses are in the dragging zone or above it. Periods of low and high loads alternate. Meaning that it is difficult to determine whether there is low-cycle or multi-cycle fatigue.

7. CONCLUSION

The assumption that the cause of damage and emergency switch is the influence of the track is confirmed. The current collectors are subjected to a large number of alternating cycles of a random nature, which leads to a strong decrease in the fatigue strength of the material.

The article analyzes the influence of the lateral rocking of the tram body on the pantograph caused by the collapse of the rail. On this basis, mathematical dependences are proposed for determining the loads in the elements of the different structures of the pantograph. A methodology for measuring the parameters of the lateral swing has been proposed. The replacement of the obtained data from the measurement in the mathematical dependences will make it possible to obtain the actual loads in certain elements and on this basis to develop a plan for their maintenance, in order to avoid their frequent failures.

ACKNOWLEDGMENT

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Traffic and Transport

RANKING OF LEVEL CROSSINGS IN THE PLANNING PROCESS TO SAFETY IMPROVEMENT USING THE VIKOR

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Abstract *– Level crossings are places where two modes of traffic intersect: road and railway. Bearing in mind that the accidents that happen to them are most often with severe consequences, there is the obligation of every society to undertake activities aimed at raising the level of safety in the zone of level crossings. These activities include the application of various technical solutions that require investments, which points to the fact that raising the level of safety at level crossings is a process that must be carefully planned. The problem arises when it is expected to determine which level crossings should be chosen to investing immediately, and which of them can be left for the next phase. In this paper, the VIKOR method was applied in order to obtain the rank of level crossings that could be used in the planning phase of the strategy for improving the level of safety at the crossings. Seven level crossings were selected and their characteristics were observed, such as the frequency of road and railway vehicles, their speeds in the crossing zone, visibility from the road to the railway tracks, the structure of road vehicles and the average annual number of traffic accidents on them. The paper shows that in the process of planning the strategy of investment in road-rail crossings, the methods of multi-criteria decision-making have a significant place.*

Keywords – Railway safety, Level crossings, Multicriteria decision making, VIKOR.

1. INTRODUCTION

Level crossings are the only places where two types of traffic meet, road and railway. Bearing in mind that the differences in the mass and speed of vehicles of these two types of traffic modes, it is clear that the consequences of traffic accidents at crossings have very serious consequences, especially for participants in road traffic. Therefore, it is necessary for each society to invest additional funds in order to raise the level of safety at level crossings.

There are two basic ways to increase safety at level crossings:
1. Using organizational measures and
2. Applying technical solutions

Organizational measures include the adoption of various regulations through laws and bylaws that regulate the right of way (all road vehicle have to miss trains), speed, visibility from road to the railway and some other parameters that affect the safety at crossings. These measures can contribute to increasing the safety of users of level crossings, but in practice they have been shown to be insufficient without additional measures.

The application of technical solutions implies technical systems which warn drivers that a train is approaching, close road traffic and ensure the safe passage of the train. The safest solution is the one that provides absolute safety, and such a solution can be achieved only in one way, by overpasses or underpasses the railway lines. This solution is the best, but it is also, the most expensive solution from the financial aspect.

In practice, it has been shown that the solution lies in a compromise between finances and an acceptable level of security. This means that, depending on the available funds, it is necessary to make a strategic plan according to which investments will be made in safety improving at level crossings.

The safety on the level crossings is affected by a number of factors. However, it is difficult to say which of the factors and how much affect the safety at the

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crossings. Also, sometimes we find ourselves in a situation where we lack data on some level crossings that are necessary to make a calculation. In such situations, we need a method that is based on the assessment and evaluation of parameters that affect the safety at the crossings. One such method is VIKOR, which is applied here in the fuzzy environment. VIKOR in fuzzy environment was applied for solving various railway infrastructure problems [1 -5].

2. MULTICRITERIA DECISION MAKING AND VIKOR

Multicriteria decision making (MCDM) is a discipline that belongs to Operational Research and is used when it is necessary to make a decision based on certain criteria that are most often conflicting. The greater the number of such criteria, the more complex the decision-making process.

There are numerous methods of MCDM process, and PROMETHEE, ELECTRE, TOPSIS, AHP and others are just some of the ones that are most used in these problems. One of the newer method that is increasingly finding a place in the scope of decision making problems is the VIKOR method (Multicriteria Optimization and Compromise Solution), which was developed to solve the problem of multicriteria optimization of complex systems [8]. It deals with the ranking and selection of alternatives from a set of alternatives and defines a compromise solution to the problem with conflict criteria.

Step 1. Defining the problem and the goal of the decision-making process - In this step the problem should be carefully defined and it should be clear what is the way out of the model.

Step 2. Define a set of final solutions and criteria on the basis of which the evaluation of alternatives is performed.

Step 3. Define a scale in the form of linguistic evaluations of criteria, as well as a group of experts from different fields, interested in the problem. Experts are performing evaluations of alternatives by criteria.

Step 4. The calculations of parameters f_j^* i f_i^- $(j = 1, 2, ..., n)$, for all chosen criteria:

$$f_j^* = \max_i x_{ij} \tag{1}$$

$$f_j^- = \min_i x_{ij} \tag{2}$$

Where x_{ij} ($i = 1, 2, …, m$) i ($j = 1, 2, …, n$) are elements of the matrix of transformed linguistic assessments according to the appropriate scale

Step 5. The calculations of the parameters S_i and R_i, $i = 1, 2, …, m$:

$$S_i = \sum_{j=1}^{n} w_j\left(f_j^* - f_{ij}\right)/(f_i^* - f_i^-) \tag{3}$$

$$R_i = \max_j w_j\left(f_j^* - f_{ij}\right)/(f_i^* - f_i^-) \tag{4}$$

Where w_j are weighted coefficients of criteria.

Step 6. The calculation of the paremeter Q_i, ($i = 1, 2, …, m$):

$$Q_i = \frac{v(S_i - S^*)}{(S^- - S^*)} + (1-v)\frac{(R_i - R^*)}{(R^- - R^*)} \tag{5}$$

Where v is the coefficient for the group of maximum benefit.

Step 7. Ranking of alternatives by parameters S, R and Q, starting from the smallest values for each of these parameters.

Step 8. Analysis and interpretation of the obtained results. In this step, the fulfillment of the conditions necessary to give preference to an alternative is examined. Thera are two conditions:

1. Accepteble advantage

$$Q\left(A^{(2)}\right) - Q\left(A^{(1)}\right) \geq \frac{1}{J-1} \tag{6}$$

Where J is the number of criteria considered in model.

2. The alternative $A^{(1)}$ must be the best ranking by parameters S and R, too

The compromise solution is adopted based on the maximum value of the parameter S (maximum utility) and the minimum damage represented by the minimum value of the parameter R. Both values are taken into account in calculation of the parameter Q for the compromise solution.

3. THE APPLICATION OF THE MODEL TO THE PROBLEM OF LEVEL CROSSING RANKING

The aim of this paper is to determine the most endangered level crossing from the group of considered crossings, comparing the selected criteria. In the level crossing chosen in this way, investments should be made in order to raise the level of safety. In this paper a group of seven level crossings is considered and marked with A1 - A7. Criteria that were considered for each crossing are: number of road vehicles using the crossing during 24 hours, number of railway vehicles using the crossing in 24 hours, average occupancy of the crossing by one train, visibility from the road to the railway, speed of road vehicles during crossing, speed of railway vehicles, whether there were traffic accidents at the crossing in the previous period and how many of them, as well as if there are side roads that joint to the road that intersects the railway, near level crossing.

Two groups of experts participated in the research, based on which the ranking process was conducted: economical and traffic engineer profession. For linguistic assessments of criteria and weighting coefficients, five-point scales were used. For weighting coefficients of criteria were used assessments: VIN -

Tab. 1. Linguistic assessments of criteria by experts

Criteria	INV (Investor)	TEN (Traffic Engineer)
C1 - Number of road vehicles	VSG	VSG
C2 - Number of railway vehicles	SIG	VSG
C3 - Level crossing occupancy by train	INS	MSG
C4 - Visibility from railway tracks to road	INS	MSG
C5 - Road vehicle speed	SIG	SIG
C6 - Railway vehicle speed)	VSG	SIG
C7 - Number of accidents	SIG	VSG
C8 - Number of access roads	VIN	INS

Tab. 2. Evaluations of individual criteria

Expert	Level crossing	Criteria							
		C1	C2	C3	C4	C5	C6	C7	C8
Expert 1	A1-Stopanja	P	VN	N	P	VP	N	SP	P
	A2-Veliki Crljeni	SP	P	N	P	P	N	P	P
	A3-Šid	P	P	SP	VP	SP	P	SP	N
	A4-Lazarevac	SP	SP	N	N	VP	N	N	SP
	A5-Laćarak	VP	SP	SP	VN	P	P	SP	SP
	A6-Gruža	P	N	SP	VN	VP	P	SP	N
	A7-Negotin	P	VN	VP	N	P	SP	P	SP
Expert 2	A1-Stopanja	VP	VN	VN	P	P	VN	SP	P
	A2-Veliki Crljeni	N	P	N	VP	SP	N	P	P
	A3-Šid	P	VP	P	VP	N	P	SP	VN
	A4-Lazarevac	SP	SP	N	SP	P	N	N	N
	A5-Laćarak	VP	SP	SP	N	SP	P	SP	SP
	A6-Gruža	P	N	SP	N	P	P	SP	VN
	A7-Negotin	P	VN	VP	SP	SP	SP	VP	SP

very insignificant, INS - insignificant, MSG - Middle significance, SIG - Significant and VSG - very significant. For evaluations of individual criteria: VN - very unfavorable, N - unfavorable, SP - moderately favorable, P - favorable and VP - very favorable. In such way, two groups of linguistic estimates were formed. The input parameters are shown in Tables 1 and 2.

A value of 0.5 is adopted for the value of parameter V. The calculated parameters of $\boldsymbol{S_i}$, $\boldsymbol{R_i}$ and $\boldsymbol{Q_i}$, as well as the obtained rank are shown in Tables 3 and 4.

In order to determine the stability of the solution, a sensitivity analysis was performed. In this analysis, the value of parameter V was changed within the interval [0, 1], with a step of 0.1. The change in the rank of the considered level crossings depending on the parameter V is shown in Figure 1.

From Table 4 it can be seen that the level crossing ***A3*** has the highest ranking according to the parameter ***Q***. Both criteria, that are necessary to be met, in order to be able to say that one alternative is superior to the other, are met here:

1. $Q(A^1) - Q(A^2) \geq \frac{1}{J-1}$,

   Where $\boldsymbol{J}$ is the number of considered alternatives and
2. The alternative A3 has the highest rank considering parameters S i R.

Therefore, the obtained result shows that according to the criteria taken into consideration, the level crossing A3 (Šid - the main railway line to Croatia) is the most endangered and this level crossing should be in that, of the observed crossings, this level crossing should be in a shortlist for investment.

4. CONCLUSION

The paper uses the VIKOR method for determining the priorities of investment in level crossings. It has been shown that this method can be easily applied to problems in which, based on the selected safety criteria of level crossings, it is possible to determine the priority of investments in raising the level of safety at them.

Tab. 3. Calculations of parameters S_i, R_i and Q_i

	Criteria										
	C1	C2	C3	C4	C5	C6	C7	C8	S_i	R_i	Q_i
A1	0.03	0.22	0.11	0.03	0.00	0.15	0.06	0.00	0.61	0.22	0.90
A2	0.11	0.02	0.10	0.03	0.04	0.14	0.01	0.00	0.46	0.14	0.38
A3	0.04	0.00	0.06	0.00	0.09	0.00	0.06	0.08	0.33	0.09	0.00
A4	0.08	0.09	0.10	0.10	0.00	0.14	0.11	0.06	0.68	0.14	0.69
A5	0.00	0.09	0.07	0.12	0.04	0.00	0.06	0.04	0.42	0.12	0.26
A6	0.04	0.16	0.07	0.12	0.00	0.00	0.06	0.08	0.54	0.16	0.58
A7	0.04	0.22	0.00	0.10	0.04	0.07	0.00	0.04	0.51	0.22	0.75

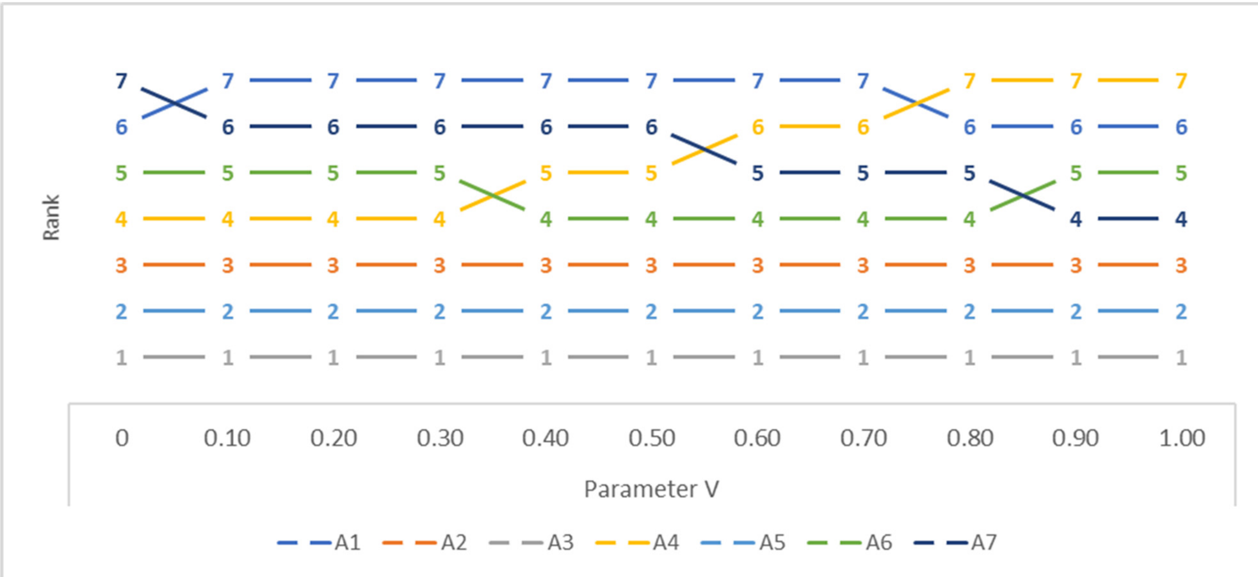

Fig.1. Sensitivity analusis of the alternative rankings depending on the coefficient V

The results suggest that this method can be applied as a preliminary method when it is necessary to, make selection of all level crossings into groups of more and less endangered (for example on one territorial unit, or on the observed railway line). In the second phase, detailed tests would be performed.

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APPLICATION OF OPENTRACK AT RAILWAYS OF REPUBLIC OF SRPSKA (RAILROAD TRACKS ŠAMAC – DOBOJ)

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***Abstract** – OpenTrack is a tool for planning and simulating railway operations. Developed at the Swiss Federal Institute of Technology in Zurich, Switzerland, and is currently supplied by OpenTrack Railway Technology Ltd. for over 230 organizations in 50 countries. Pre-defined trains run in accordance with the timetable data on the defined track topography. The simulation has both continuous and discrete parts. The continuous part calculates the differential equations for train speed and distance. The discrete part simulates processes such as the state of the signal system and possible delays. During the simulation, the user can view the track topography in animation mode showing trains, prepared routes and current aspects of the signal. The user can terminate the simulation at any time and, if necessary, enter OpenTrack and change certain restrictions. This work describes the application of OpenTrack on the Railways of the Republic of Srpska for the railway from Doboj to Šamac and the state border with the Republic of Croatia.*

Keywords - Simulation, Railway Operation, Timetable.

1. INTRODUCTION

Following the European and world trends in railway traffic planning and research of the relationship between the volume of traffic and traffic infrastructure on which it takes place, the Railways of RepublikaSrpska in 2017 decided to introduce a simulation method in their planning procedures, primarily for the development of timetable elements.

The software for traffic simulation on the railway network, developed by the Swiss Federal Institute of Technology in Zurich, is one of the generally accepted simulation software among experts engaged in planning and research in the field of railway transport. By 2019, this software was accepted by more than 230 organizations in over 50 countries. In the last ten years, it has also been used by railway experts from the neighbouring countries, ie Serbia, Croatia and Slovenia.

Although done as "user friendly", working in this software requires highly professional multidisciplinary knowledge of railway structural elements (stable and mobile capacities) and the way they function, as well as knowledge of the organization and technology of railway traffic.

The railway section from the Šamac station to the Doboj station was chosen for the pilot project of modeling and simulation of railway traffic in the OpenTrack software. The length of the railway Šamac - Doboj is 60.6 km and according to the category of the railway it belongs to the group of main auxiliary (M-P). The maximum speed on this section of the railway is 50 km / h from 2014. In the same year, Republika Srpska was hit by major floods that caused damage to the upper and lower parts of the railway, so that after the rehabilitation of the railway, the speed was reduced from 70 km/h to 50 km/h because the characteristics of the railway do not allow higher speeds. The reason why this section of the railway was chosen is because the railway is electrified and the closest connection with Croatia, and therefore with Europe. This section of the railway is also part of the Vc corridor.

2. MAIN CHARACTERISTICS OF THE OPENTRACK SOFTWARE

For modeling and simulation of complex multidisciplinary railway processes in the world today there are dozens of software and tools that allow the

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creation of macro, meso and micro simulation models, and the possibility of simulating discrete or continuous processes.

Simulation software OpenTrack is one of the few softwares that essentially allows the creation of macro-simulation models (there is no limit to the size of the railway network being modeled) with all the characteristics of micro-simulation models, because it allows modeling with a high attention to detail and monitoring of all structural and functional elements of importance for railway traffic. In addition, this software enables parallel simulation of discrete and continuous railway processes, as well as modeling and simulation of Maglev, metro and tram systems. OpenTrack has a complex modular structure that can be most simply described as a system consisting of an input data module, a simulation module, and an output data module (Figure 1) [1].

For process management purposes within the software, the data and information entered are classified into three different file types: documents, databases, and output. The software uses six different databases (on traction vehicles, train composition, official places, routes, train paths and timetables). All data, which is entered via the "user friendly" interface of these modules, is defined by the user [2].

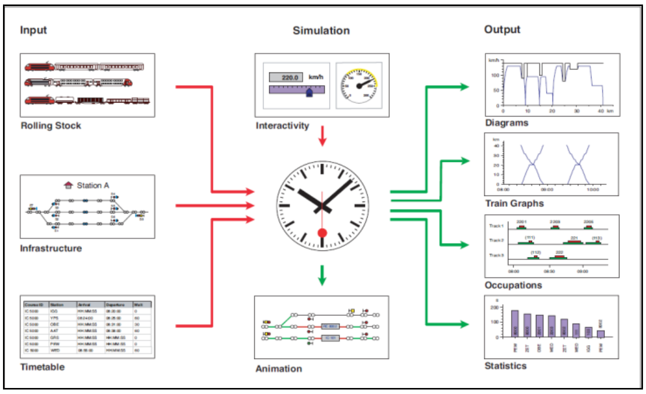

Fig.1. OpenTack structure: Input - Simulation - Output

The vehicle module enables the entry, storage and management of vehicle data (towing and towed vehicles). The technical specifications of each individual towing vehicle such as towing force, towing force, diagram of change of towing force and power according to speed (towing passport), coefficients of adhesion, mass, length, acceleration and selection are entered into the database on towing vehicles (depot). are the formulas for calculating motion resistance. The required data on towed vehicles are length and weight, so they can be entered individually from the bill of lading or collectively for the entire composition. Accordingly, the train composition is modeled by selecting one or more traction vehicles from the base and attaching data on vehicle mass and length, braking percentage and train category (rank), which determines the priority when moving through the infrastructure model in progress.

The infrastructure module enables graphical modeling of all elements of infrastructure important for train movement on the principle of the graph method with double points of change of value ("vertex")[1] and lines connecting them ("edge")[2].These points and lines are the basic elements for modeling tracks, switches, signals, security systems, road crossings, power supply systems, train stops, etc. and their individual attributes. Attributes are added via menus in whose fields are entered: object name, stationing, level slope, radius of curvature, maximum speed of train traffic over each individual element of the line by train categories. In this way, the railway is modeled according to the real parameters of the longitudinal profile and stationations of buildings, tracks, track plants and devices. Signaling is modeled according to all functional specifications [1].

In order to perform the simulation of train movement in the model, it is necessary to enter, store and manage train traffic data, ie it is necessary to define the route for each train (by track and station tracks) and timetable elements, at least departure time from the departure station, minimum time of dealing in stations and at stops or other places where it is necessary, places of crossing and overtaking trains, turns of locomotives and sets, etc.). During the simulation, the equations of train movement are calculated and the driving time is obtained as one of the results. The output results of the simulation can be displayed in several different ways, and are most common by train, route or station. During the simulation, a virtual tachograph is created for each train, as an output file, which contains data on acceleration, speed and distance traveled. Also, the output results can be presented in the form of timing diagrams, timetable graphs, station track occupancy schemes and various statistics shown both graphically and tabularly.

3. MODELING AND SIMULATION OF THE SAMAC-DOBOJ RAILWAY

The application of modern tools in scheduling planning is extremely important, especially when it comes to railways where there are several factors in planning, which requires a long process of harmonization. Railway: Šamac - Doboj (Figure 2) is single-track, electrified 25 kW and 50Hz and provided with inter-station dependence devices. The traffic of successive trains on the line takes place at the station distance. The track is of category D4, capable of a load per axle of 22.5 kN and 80 kN per meter [5].

---

[1] *The point of change of parameter values.*

[2] *A line that connects the points where the parameter values change.*

Fig.2. Scheme of the railway Shamac - Doboj

There are:

- 5 stations: Šamac, Modriča, Osječani, SrpskaKostajnica and Doboj.
- 2 crossroads: Vranjak and KoprivnaGornja,
- 9 stops: Miloševac, Garevac, Brvno, KoprivnaDonja, Kožuhe, Vasiljevići, Bušletići, KostajnicaDonja, KostajnicaGornja.

The maximum allowed speed on the railway (according to the timetable for 2019/2020) is 50 km / h. The stopping distance is 1000 m, the minimum radius of curvature is 250 m while the maximum radius of curvature is 40,000 m. The relevant resistance on the railway is 7 ‰ and is located between the intersections KoprivnaGornja and Vranjak [4].

4. DATA PREPARATION AND MODELING IN OPENTRACK

Data for model development are provided from databases and records of company services, namely: Sector for construction works (written longitudinal profile of the railway, data on stationing and radius of curves and transition curves in tabular form, station schemes, data on limited speeds and easy rides and etc.), Sector for electrical engineering (data on signaling and safety devices on the line and in stations by type and stationing, stationing and level of securing road crossings in the level), Sector for towing trains (data on towing vehicles in the active park and their technical exploitation characteristics), Sector for exploitation (Timetable booklet and STU with timetable), etc. [5].

The modeling of the railway was done in phases, filling in the required database one by one. Thus, a model of infrastructural elements was first made: station and railway tracks, signals, etc. with the entry of their attributes in the databases (Figures 3, 4, 5, 6 and 7) and the creation of a database of official places [3].

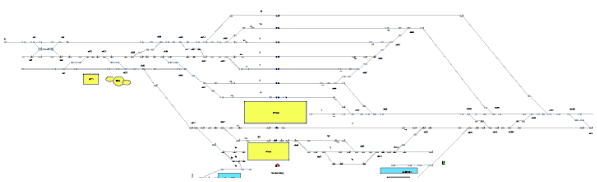

Fig.3. Model of the Doboj station in OpenTrack

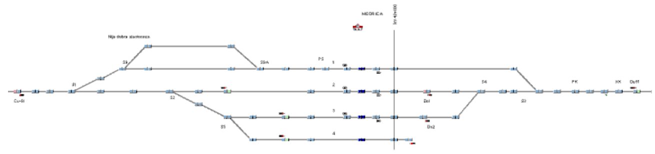

Fig.4. Model of Modriča station in OpenTrack

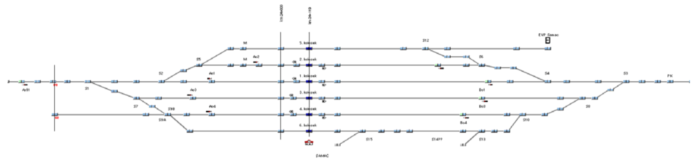

Fig.5. Model of the Šamac station in OpenTrack

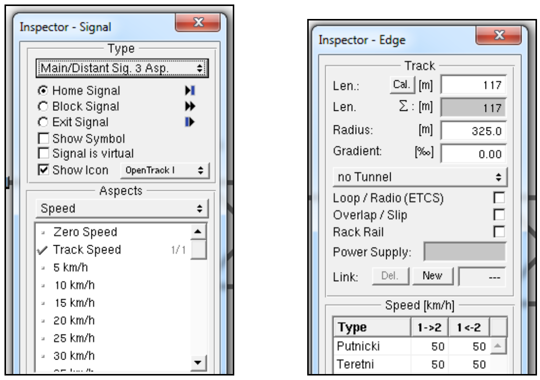

Fig.6. Attributes of the input signal and the part of the track behind the input signal to the Doboj station

Then the construction elements are grouped into safety elements: paths, routes (Figure 7) and itineraries (Figure 8).

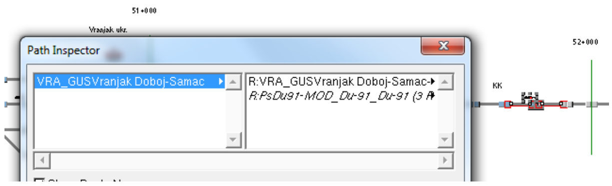

Fig.7. Entrance routes to the Vranjak intersection

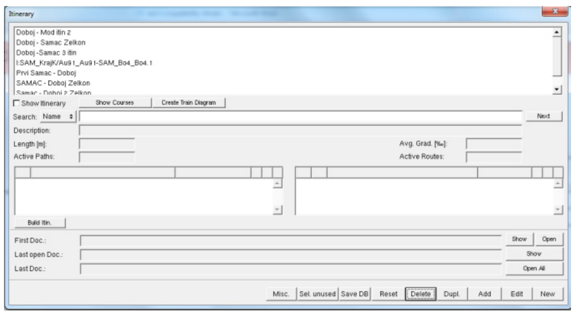

Fig.8. Itineraries for train movement on the Shamac-Doboj line

Then the base of towing vehicles was made (Figures 9 and 10).

After that, the base of rolling stock was made at the end of the train base by assigning numbers and itineraries to the rolling stock.

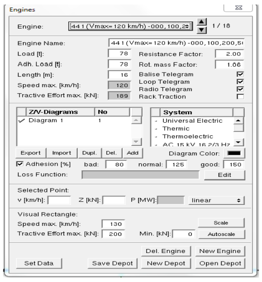

Fig.9. Data on locomotive 441 in depot base

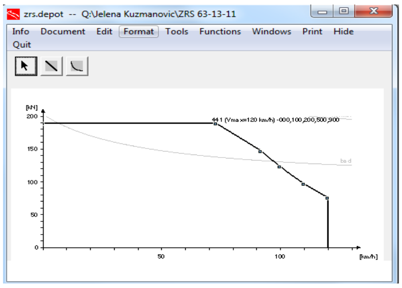

Fig.10. Towing passport of locomotive 441 in depot base

Finally, the trains are assigned the basic elements of the timetable (departure time from the departure station and time spent in official places on the line) so that during the simulation calculations of train equations get the travel times and arrival times at each station and departure from each station. located in output databases.

5. CALIBRATION VERIFICATION AND MODEL VALIDATION

The model was verified by zero simulation. It was determined that the model behaves according to all principles and rules that apply in railway traffic, ie. active infrastructure elements (switches, signaling devices) react to the given train paths and the train movement through the model is identical to the train movement in the real system [3].

Validation, ie evaluation of the validity of the model was done by comparing the output data of the simulation on the driving time of the passenger train 6451 and the freight train 48820 with the data from the real system, ie with the data from the actual chart. The driving times were found to be very close to the driving times recorded in the actual graphs. Then, a simulation of all trains for good and bad operating conditions was planned and done, for a period of 24 hours. Simulation experiments were performed several times to confirm the identity of the output results.

6. CONCLUDING REMARKS

For traffic planners and traffic infrastructure (track capacities, signalization, electrification, etc.), the application of modern sophisticated methods and tools is very important, and above all the application of the simulation method on the model. By applying the OpenTrack software, it is possible to create various traffic scenarios in the present and future in a simple and fast way on the built model. Also, it is possible to make a model of planned modifications of the elements of the existing infrastructure or a completely newly designed infrastructure and monitor the relationship between the volume of traffic and the traffic infrastructure on which it takes place. In addition, this software enables the simulation of various traffic disturbances, which enables other "if-then" research. The results of the research are, above all, considered as additional arguments for decision-making in the development of various operational, tactical and strategic plans. It has been shown that the method of simulation on the model is especially suitable in the conditions of market liberalization, where the relationship between the operator and the owner of the infrastructure is based, primarily on the lease of the route. So simulation software can benefit both infrastructure owners and operators. As the timetable is an act of the infrastructure manager, and the calculation of route elements should be based on real data on train composition (towing and towed vehicles) owned by the operator, it is necessary for both parties to provide data on order elements in a simple and fast way driving which can only be realized by simulating the traffic of the desired train through a defined infrastructure. Also, for the section of the railway that has been selected and tested, it is possible to place in the program all those elements that are planned to be installed on the corridor Vc and see the effects that are achieved, which is extremely important for our small railway.

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CLASSIFYING COUNTRIES FOR RAILWAY PERFORMANCE BENCHMARKING: A HIERARCHICAL CLUSTERING APPROACH

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Katarina HALAJ[2]
Mira PASKOTA[3]

Abstract *– Interest in benchmark analysis of railway performance and efficiency has significantly grown in recent years. This paper proposes a methodology for defining benchmark countries in terms of railway performance on the basis of hierarchical cluster analysis. The hierarchical cluster analysis is a multivariate statistical method that is used for the classification of objects according to their (dis)similarities in different groups called clusters. The analysis is conducted among 29 European countries for data obtained for the year 2018.*

Keywords - railway performance, hierarchical cluster analysis, benchmarking analysis

1. INTRODUCTION

In recent decades, the performance and efficiency analysis of various aspects of the railway system are in the focus of researches. This previous work included also studies about benchmark analysis of railway companies or authorities as well as identification of best practices for improving the efficiency of these entities. But comparing railway performance and identification of peers ie something of equal worth or quality, represents two different aspects in this type of studies.

The robust methodology for railway performance classification gets a little attention in the extant literature. In most of the papers, this classification was done on ad hoc criteria.

The aim of this paper is to propose a methodology for the classification of railway systems based on their performance to identify peers or benchmarks as the first step in benchmark analysis. The data is gathered for 29 European countries for the year 2018. We want to show real competitors among these 29 countries and enable robustly and reliable benchmarking.

The paper is structured as follows. Section 2 presents a review of some previous benchmarking analysis of railway performance. In section 3 the methodology for classification and dataset is introduced. Section 4 provides empirical results of classifications and discussion. Finally, the main conclusions and further research are presented in Section 5.

2. BENCHMARKING OF RAILWAY PERFORMANCE

There are a lot of answers to the question: What is benchmarking? We chose the definition from a book [1] that says*: „Benchmarking is a method of measuring and improving our organizational performance by comparing ourselves with the best“*. The term *measuring* implies that we need to conduct a comparison of performance levels with defined peer. The term *improving* defines the need for identification and adoption of the practices that will improve the current level of performance.

Regarding the railway sector, there are several benchmarking studies among different entities. In [2] authors conducted a benchmarking analysis among 11 mid-size European railway networks and undertakings in the year 2009. In the first part, the authors investigated available data regarding infrastructure and transport indicators. In the second part, they used Data Envelopment Analysis for measuring network productivity, operating efficiency of infrastructure managers and passengers railway undertakings. Benchmarking analysis among 10 European freight railway undertakings for different years in the period 2001-2004 (which depended on the availability of data) was done in [3]. The authors examined on which extent the efficiency of rail freight transport could be improved. They used mixed (multilevel) modeling approach to analyze trends of selected indicators and after that identified the best and worst performing

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company for each indicator. Also, the authors described some possible strategies for increasing efficiency as well as reasons for a disappointing performance in observed fields. Authors in [4] tested the efficiency of railway operations of 35 countries within Belt and Road initiative. In the first stage, they applied DEA on two different datasets to calculate the relative efficiency of railway systems. In order to find benchmark countries with lower performance, authors conducted network analysis. Analysis of 4 European and 4 Asian high-speed railway networks for the period 2007-2012 was done in [5]. The selection of high-speed networks was done based on actual travel volume over the observed timeframe. The author applied Network Data Envelopment Analysis (NDEA) in combination with the Malmquist Productivity Index as a method for benchmarking analysis. In addition, he developed a performance matrix to identify and propose a strategy for increasing efficiency. From the reviewed papers, the following can be highlighted.

The main limitations for good benchmarking analysis were non-existence of enough proper publicly available data, inconsistencies between different databases and reports, the limited number of countries or companies, different work culture and approach to railway systems. Also, in most of the papers, benchmarking analysis was conducted straightforwardly, without any grouping and identification of more precise efficiency benchmarks. Bearing in mind the complexity of the railway system and scope of technological and regulatory operation, defining appropriate benchmarks is a thankless job. So, in order to address this issue, we propose a method that will classify railway systems in different groups generated by a measure of similarity among the established set of indicators. This will define real competitors within groups and better comparative analysis which will lead to a more reliable benchmarking process.

3. RESEARCH METHODOLOGY AND DATA

3.1. Hierarchical cluster analysis

If data are represented as an n×p matrix X, the goal of cluster analysis is to develop a classification scheme that will partition the rows of X into k distinct groups, which we call clusters. The rows of the matrix usually represent observations. In many applications of cluster analysis, one begins with a proximity matrix rather than a data matrix. Given the proximity matrix of order n×n say, the entries may represent dissimilarities between the r^{th} and s^{th} observations [6]. Hierarchical clustering is a method of cluster analysis which seeks to build a hierarchy of clusters. Under hierarchical clustering, the number of clusters is unspecified and generated from the observed data. This method results in groups of related observations that can be visualized with a dendrogram, a tree-based two-dimensional plot.

Hierarchical cluster methods can be categorized into agglomerative and divisive clustering methods. Agglomerative methods start by taking singleton clusters (that contain only the one observation per cluster) at the bottom level and continue merging two clusters at a time to build a bottom-up hierarchy of the clusters. Divisive method, on the other hand, is the opposite of agglomerative clustering in which clustering starts with a single cluster and split it continuously into two groups generating a top-down hierarchy of clusters. [7][8]

This paper focuses on hierarchical agglomerative clustering. The algorithm composed of the following steps:

1. Find the proximity matrix.
2. Find the most similar pair of objects (observations) from this matrix.
3. Combine these two objects into a new (composite) object.
4. Calculate the dissimilarity of this composite object with the remaining objects.
5. Repeat steps 2 - 4 considering both initial objects and composites of objects.
6. Stop the procedure when there are no more objects to combine or when some criterion has been reached.

In order to decide which clusters should be combined a measure of dissimilarity between sets of observations is required. This is achieved by the use of an appropriate metric (a measure of the distance between pairs of observations) and a linkage criterion which specifies the dissimilarity of sets as a function of the pairwise distances of observations in the sets. [9]. Some commonly used metrics for hierarchical clustering are Euclidean, Manhattan, Mahalanobis distance, etc.

The linkage criterion determines the distance between sets of observations as a function of the pairwise distances between observations. Some commonly used linkage criteria between two sets of observations are complete linkage clustering, single linkage clustering, average linkage clustering, Ward’s criterion, etc.

3.2. Data sources and dataset

In order to perform the clustering process, we introduced indicators that properly explain the performance of the railway sector of specific countries. As source for indicators data, Eighth Market Monitoring report prepared by Independent Regulators’ Group for Rail was used [10]. This report is covering the data for 2018. On the basis of the report, 8 indicators for 29 European countries were defined.

Tab. 1. Descriptive statistics of indicators

Indicator	Unit	Description	Mean	Standard Deviation	Minumum	Maximum
RL	km	Length of railway network	7996,96	9045,63	271	39299
PRU	Number	Passenger railway undertaking	12	26,46	1	142
FRU	Number	Freight railway undertaking	24,55	45,30	1	234
FS	Trains per day per route km	Network usage intensity for freight services	8,97	6,08	1	25
PS	Trains per day per route km	Network usage intensity for passenger services	39,14	32,73	5	136
TRT	Million train km	Total rail traffic	156,79	231,58	1	1116
FT	Billion net tonne km	Freight traffic	16,28	25,43	0,3	131.8
PT	Billion passenger km	Passenger traffic	17,03	26,,78	0,1	99.9

A descriptive analysis of the indicators is presented in Table 1. Classification of railway systems based on defined indicators was done in SPSS (Statistical Package for Social Science). As the clustering method in SPSS was chosen an average-linkage algorithm supported with the Euclidean distance metric. In this algorithm, each step merges the nearest two clusters according to the average distance among their components. We chose this way of clusterization following the methodology in papers [11] [12] in which different ports and airports were classified according to their performance.

4. EMPIRICAL RESULTS AND DISCUSSION

As an output of the clustering process, we get an agglomeration schedule and a dendrogram. The purpose of the agglomeration schedule is to help the researchers to identify at what point the two clusters that are combined are considered too different to form a homogeneous group and that it would be ideal to stop the clustering process before the clusters become too heterogeneous. The clustering process in this study was stopped after stage 24 and we eliminate the last 4 stages as it is presented in a dendrogram in Figure 1.

The railway performance dendrogram is creating a new dimension in process of comparison of different railway systems. Dendrogram effectively defines proper benchmarks within the observed framework of indicators. Dendrogram in Figure 1 identifies six specific clusters. The first cluster consists of Austria and Slovenia whose railway systems are similar in network usage intensity for freight services which sets them apart from other clusters. The second cluster includes 19 countries. Third and fourth consist of 2 countries each: the Czech Republic and Poland, Netherlands and Switzerland respectively.

The Czech Republic and Poland are characterized by a large number of freight railway undertakings, and Switzerland and the Netherlands by a network usage intensity for passengers services. The fifth cluster includes only Germany. In this study, Germany can be considered as an outlier. The Italy, United Kingdom and France are part of the sixth cluster characterized by high level of total traffic with perfomance of freight and passenger traffic that separates them from other clusters.

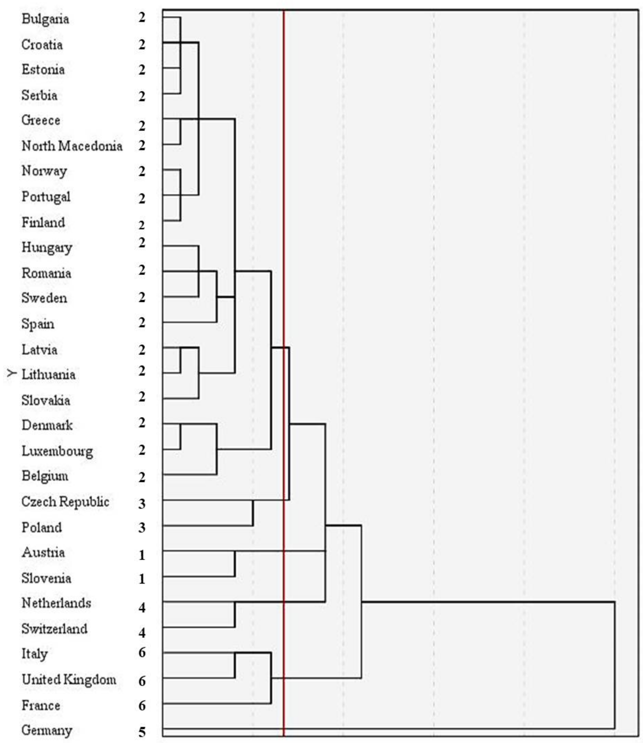

Fig. 1. Railway perfomance dendrogram

Tab. 2. Descriptive statistics of clusters

Average Linkage		**RL**	**PRU**	**FRU**	**FS**	**PS**	**TRT**	**FT**	**PT**
Cluster 1	Mean	3.428,5	8,5	20,0	25,0	39,0	93,0	14,5	7,0
	Std. Deviation	3.141,7	10,6	24,0	0,0	22,6	101,8	13,1	8,9
Cluster 2	Mean	4.505,9	3,1	9,1	6,5	27,5	54,9	7,6	5,0
	Std. Deviation	3.942,2	2,7	9,9	3,6	23,7	54,4	7,0	6,7
Cluster 3	Mean	14.437,0	17,0	80,5	11,5	31,0	213,5	38,1	15,6
	Std. Deviation	6.887,2	8,5	9,2	0,7	11,3	57,3	30,4	7,5
Cluster 4	Mean	20.983,0	16,7	18,0	6,3	58,3	461,7	24,1	70,9
	Std. Deviation	6.330,6	11,4	8,7	0,6	28,0	98,3	7,5	17,5
Cluster 5	Mean	39.299,0	142,0	234,0	19,0	59,0	1.116,0	131,8	99,9
	Std. Deviation	-	-	-	-	-	-	-	-
Cluster 6	Mean	4.160,0	23,0	25,5	12,5	119,5	194,5	9,4	20,1
	Std. Deviation	1.562,7	15,6	0,7	3,5	23,3	44,5	3,5	0,7

We performe a descriptive analysis of identified clusters presented in Table 2. Cluster 2 and Cluster 5 are very similar in length of the railway network but very heterogeneous in all other indicators, especially in performance. Also, Table 2 shows why Germany needs to be considered as an outlier in the observed dataset. Cluster 3 and Cluster 4 have almost the same number of undertakings that perform passenger transport, but the performance indicatorsare on the side of Cluster 4 and for that reason, the countries from that cluster would not be good benchmarks for countries from Cluster 3.

4. CONCLUSION AND FUTURE RESEARCH

This paper introduces the issue of the clusterization of railway systems within benchmarking analysis and proposes a methodology based on the agglomerative hierarchical clustering algorithm.

In order to perform the clustering algorithm, eight railway performance indicators for 29 European railway systems were developed. The clustering process resulted in six clusters among which an outlier in the form of a German railway system was identified.

As mentioned in the paper, this is the first step in railway benchmarking analysis. Accordingly, future research will address the selection of methodologies for measuring performance and determining best practices within clusters with special emphasis on improving the performance of the railway system in Serbia.

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XIX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
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HAZARDS AND RISKS DUE TO TANK CAR EXPLOSION

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Abstract *– The most common mode of continental transport of dangerous good is by railway. Hazardous substances in fluid state are exclusively transported by tank cars. Tank cars explosions are rare accidents, but with very high consequences and significant transport risk. This paper presents safety hazard zones with an emphasis on tank car fragmentation. The most common number of fragments generated by a tank car explosion is two or three. The shapes and masses of the fragments were evaluated according to a scientifically verified procedure. Accident risk cannot be completely eliminated, it can only be reduced to an acceptable level. The safety zone for a tank car volume of 50 m^3 with a Liquefied Petroleum Gas (LPG) is over 800 m from accident site. The probability of impact in the target of base to 10 m^2 at distances up to 800 m does not exceed $1.5\cdot10^{-3}$.*

Keywords – Hazard, accident, risk, tank car, explosion.

1. INTRODUCTION

Explosion of process equipment is most often due to the BLEVE effect or mechanical damage [1-2]. The risk assessment due to fragmentation of pressure vessels requires adequate hazard modeling, and the creators of the first fragmentation models were Moore and Baker [3-4]. Holden and Reeves show that fragmentation in 77% of accidents is the result of explosions of pressurized vessels with the generated number of fragments from 1 to 9 [5]. Holden found that 60% of the generated fragments cover a sectoral angle of $\pm 30^0$ on both sides of the tank [6]. Some recent studies are based on the results of these studies [7-8]. Djelosevic and Tepic suggest an probabilistic model for estimating the number of fragments [9].

Typical explosions of tanks monitored by industrial accidents are related to the BLEVE phenomenon [9-10]. The risk assessment due to the fragmentation of the tank involves modeling the flight of the fragment, and the literature for the analysis of fragmentation exclusively uses a simplified model [11]. Gubinelli et al. use the mentioned simplified model, but do not specify the limits of its application [12]. Application of this model requires knowledge of initial conditions, such as initial velocity. Baum performs a series of experiments with tanks weighing up to 82.5 *kg* and concludes that the initial velocity does not exceed 54.6 *m/s* [13]. The size of the tank has no effect on the number of generated fragments [14]. However, by changing the size (mass) of the tank, the initial velocity changes. Baum shows that the share of the kinetic energy of the fragment can be up to 20% of the expansion energy [13]. Tugnoli et al. the uncertainty of the direction and intensity of the initial velocity of the fragment is analyzed by stochastic variables integrated into the Bayes framework [15].

The mechanism of fragmentation of the tanks is exclusively considered in the literature experimentally on samples of smaller dimensions or in the context of available accidents. Such an approach does not perceive all aspects of this multidisciplinary problem, since the high degree of uncertainty of fragmentation parameters is limited by research potential. In the continuation of the paper an original methodological approach based on a probabilistic simulation model for identifying the fragmentation mechanism is presented in the context of the elimination of epistemic uncertainty [16].

2. CRITICAL ZONE OF TANK CAR

Horizontal cylindrical tanks for LPG transport are responsible technical systems designed according to EN 13445-3 [17]. The exploitation characteristics and achieved quality of production are checked by testing the tank according to EN 13445-5 [18]. The two-axis stress state of the tank indicates longitudinal and radial deformation of the shell. The analysis of stress state of the tank is an integral part of design activities in terms of fulfilling the exploitation requirements.

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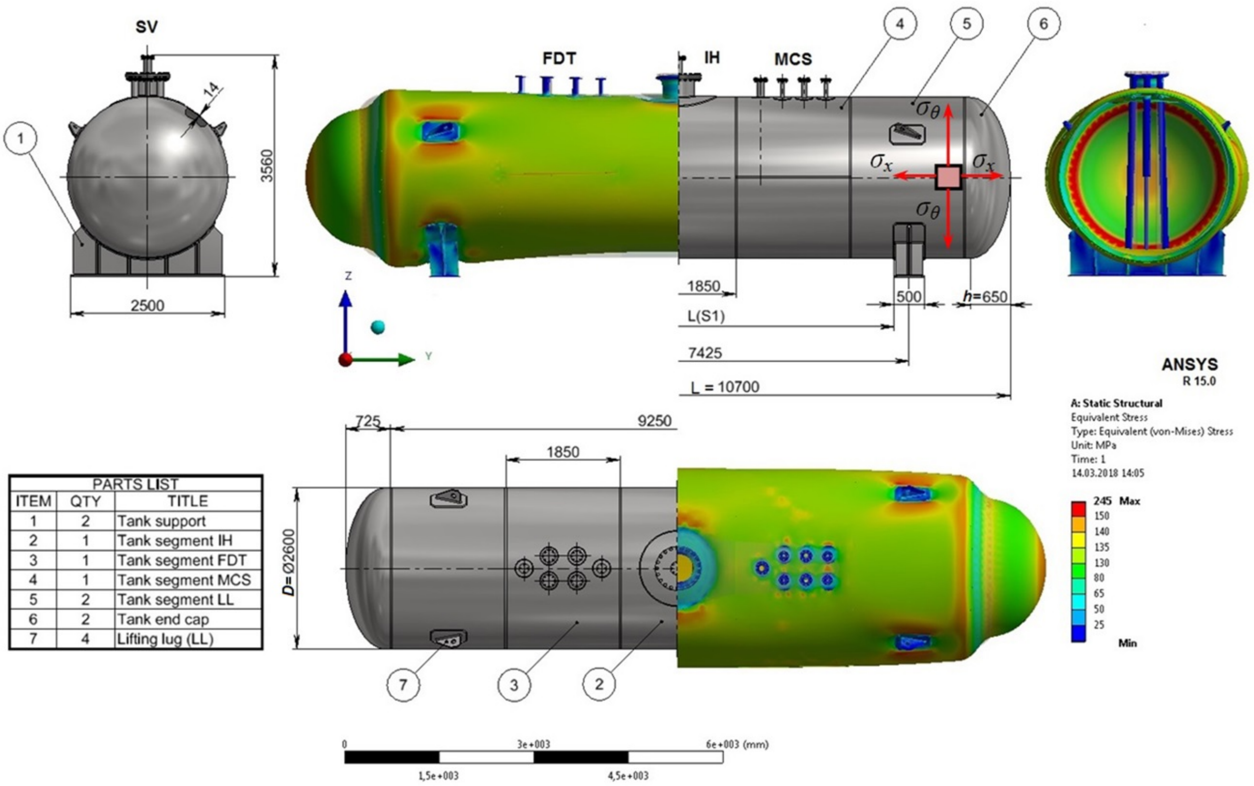

Fig. 1. Construction type of the tank and division into segments according to critical stress zones [9]

The construction of the tank consists of supports (item 1), cylinder segments (items 2-5), elliptical end caps (item 6) and lifting lugs (item 7). The tank is supplied with a filling and discharging system (FDT), a measure and control system (MCS), an inspection hatch (IH), and a safety valve (SV). The empty tank mass is 12,300 *kg* and provides storage of up to 50,000 *l* of TNG.

Exact analytical expressions for the stresses of the considered axially symmetric cylindrical tank with elliptical end caps according to [19], are:

$$\sigma_x = \left[1 + \frac{3}{2}\frac{1}{\sqrt{3(1-\nu^2)}}\left(\frac{D}{2h}\right)^2 e^{-\lambda x}\sin(\lambda x)\right]\cdot \left(\frac{Dp}{4\delta}\right) = 46.5p \tag{1}$$

$$\sigma_\theta = \left[1 + \frac{1}{4}\left(\frac{3\nu\sin(\lambda x)}{\sqrt{3(1-\nu^2)}} - \cos(\lambda x)\right)\left(\frac{D}{2h}\right)^2 e^{-\lambda x}\right]\cdot \left(\frac{Dp}{2\delta}\right) = 92.5p \tag{2}$$

$$\sigma_{cr} = \sqrt{\sigma_x^2 + \sigma_\theta^2 - \sigma_x\sigma_\theta + \frac{3}{2}(\sigma_x - \sigma_\theta)^2} = 98\cdot p_{cr} \tag{3}$$

$$\lambda = \sqrt[4]{\frac{12(1-\nu^2)}{D^2\delta^2}} \tag{4}$$

Authoritative stress for sizing the tank under stress is given by (3). The maximum permissible tank stress f is determined based on the material type (S355J2G3) according to EN 13445-3 [17]:

$$f = \min\begin{Bmatrix} R_{eH}/1.5 \\ R_m/2.4 \end{Bmatrix} = \min\begin{Bmatrix} 355/1.5 \\ 470/2.4 \end{Bmatrix} = 195.83\ MPa \tag{5}$$

The maximum permissible operating pressure is determined from (3), accordingly (5) and amounts $p_{theory} = 2\ MPa$. This pressure according to EN 13445-3 amounts: $p_{EN13445\text{-}3} = 2\cdot f\cdot z\cdot e_a/D_m = 2.12\ MPa$, where is mean diameter of the tank $D_m = (D\text{-}e_a) = 2586\ mm$, the thickness of the sheet $e_a = \delta = 14\ mm$ and coefficient of welded seam $z = 1$ (complete control of welded seams). The calculation of maximum operating pressure according to EN 13445-3 is practically the membrane stress in radial direction corrected by factor *z*.

3. FRAGMENTATION MODEL

The flight of all fragments is realized under the influence of inertial, gravitational and thrust forces, as well as the forces of air resistance. The dynamics of the flight of the fragment which has mass m_{fr} and velocity v_{fr} is described with the ordinary differential equation:

$$m_{fr}\cdot\frac{d\vec{v}_{fr}}{dt} = \vec{F}_D + \vec{F}_L + \vec{G} \tag{6}$$

The force of the air resistance during fragment's flight is defined by the expression:

$$\vec{F}_D = -\left(\frac{1}{2}\rho_v C_D A_D v_{fr}\right)\cdot\vec{v}_{fr} \tag{7}$$

The thrust force during fragment's flight is:

$$\vec{F}_L = -\left(\frac{1}{2}\rho_v C_L A_L v_{fr}\right)\cdot \vec{v}_{fr} \tag{8}$$

The trajectories are analyzed in the vertical plane *Oxz* of the local coordinate system *Oxyz* (Fig. 2). It can be shown easily that the final form of the equation of fragments motion:

$$a_{x,fr} = a_{drag}\cdot(-\cos\varphi) + a_{lift}\cdot(-\sin\varphi) \tag{9}$$

$$a_{z,fr} = a_{drag}\cdot(-\sin\varphi) + a_{lift}\cdot(\cos\varphi) - g \tag{10}$$

$$\varphi = arctg\frac{\left(\frac{k_L}{k_D}\right)\cdot(-a_x) + (-a_z) - g}{\left[(-a_x) + \left(\frac{k_L}{k_D}\right)\cdot a_z + g\right]} \tag{11}$$

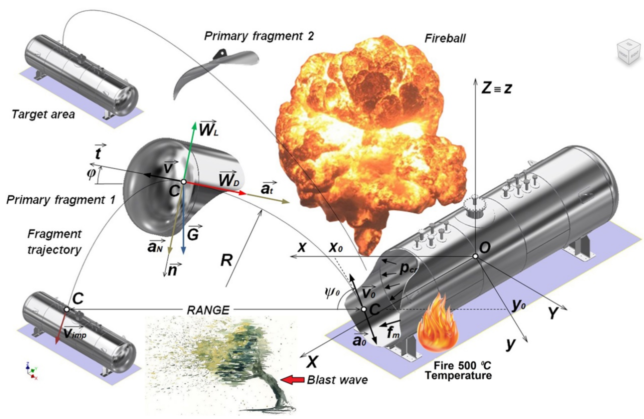

Fig. 2 A typical explosion of the tank (BLEVE effect)

The uncertainty in defining the launching angle of the fragment results from the dissipation of inputs (a_0, k_L i k_D) and is eliminated by representing the range in the form of a probability density function (Fig. 3).

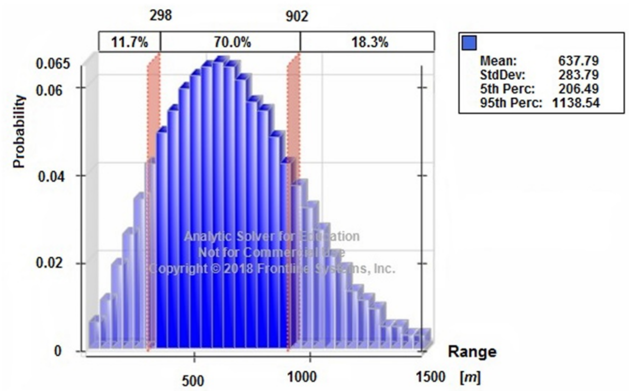

Fig. 3. Pdf for range of the fragment

4. RESULTS AND DISCUSSION

Accidents that are accompanied by explosion of the tank are distinguished by three effects: blast wave, thermal radiation and fragmentation.

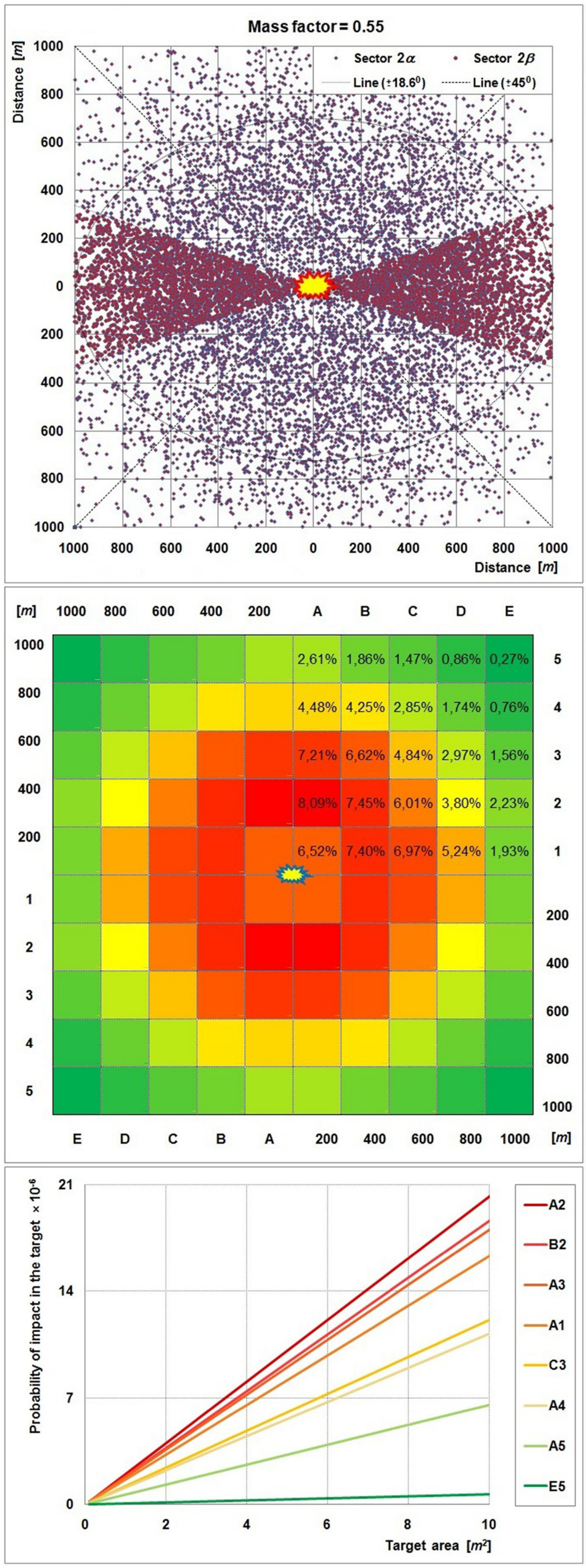

Fig. 4. Risk matrix and probability of impact

The most pronounced effect of the explosion of the tank relates to fragmentation, since the range of fragments can reach 1 *km*. The risk assessment for quadrant gabarits of 200×200 *m* within the area of ×2 km^2 was realized by simulating the generated fragments using the Monte Carlo model. The range of generated fragments is best described by the Weibull distribution with the highest probability of occurrence in the range of 600 *m* to 650 *m*. The probability of impact in the target areas of the base of about 10 m^2 at distances up to 600 *m* does not exceed $2.1 \cdot 10^{-5}$.

5. CONCLUSION

The paper presents the original fragmentation model for the identification of the kinematic parameters of the fragments generated by the explosion of a cylindrical tank. The introduction of initial acceleration is a novelty in the proposed model and allows a reliable assessment of the velocity of the fragments. Such an approach provides the ability to assessment the velocity of the fragment at the same time indicating that this parameter is not followed by an aleatoric uncertainty. Thus, in the absence of data on the initial launching angle φ_0 of the fragment, the literature assumes a uniform distribution from which its aleatoric uncertainty arises (each value for φ_0 has the same probability). However, the fragmentation model shows that the initial launching angle φ_0 depends on the initial acceleration and the aerodynamic characteristics of the fragment. This suggests that the parameter follows the epistemic rather than the aleatoric uncertainty, since the lack of literature information is the result of insufficient exploration of the fragmentation model.

The initial acceleration determines the geometric characteristics of the tank (R_m, δ i ρ), while the coefficients of thrust and resistance acceleration (k_L and k_D) are defined by the shape of the fragment. The work in a unique and original way using the Monte Carlo simulation analyzed the fluctuation effect of air resistance and thrust during the fragment flight. Distributions of the probability density for the range of fragment of mass 200 *kg* are determined. Increasing the launching angle leads to a reduction in the range of the fragment. The maximum range of a fragment of mass 200 *kg* corresponds to the launching angle up to $\varphi_0 = 35^0$.

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ASSESSMENT OF THE DEGREE OF SAFETY AT RAILWAY CROSSINGS IN SERBIA CONDUCTED BY DRIVERS

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Abstract – *The approach to this research consists of conducting a field survey of drivers in Serbia in order to collect data based on which this paper assessed the driver's knowledge of the level of safety at railway crossings. The survey provided a sample of 389 questionnaires at 15 railway crossings in different cities in Serbia. The aim of this paper is to investigate the subjective sense of driver safety, their knowledge of the local railway crossing, trust in the existing protection systems, as well as their assessment of the need to upgrade the level of protection, installing video surveillance and the use of some advance warning signs*

Keywords – railway crossing, field survey questionnaire, safety, drivers

1. INTRODUCTION

Active warning devices increase the level of safety at a railway crossing relative to passive crossings, but because exposure at active crossings is higher than at passive crossings, the accident rate is still high. The perceived credibility of the warning system is determined not only by the waiting time but also by the number of false alarms or missed signals. Even though both false alarms and missed signals contribute to the drivers' perception of the warning signals' reliability, generally false alarms at grade crossings result in a lack of compliance whereas missed signals lead to more cautious behavior [1]. Wilde, et al. [2], recorded the signal reliability of active warning devices as part of his observational study of incidents at grade crossings, as previously described. The data indicated that false alarms at the grade crossings observed were relatively infrequent.

Limited sight distance to the crossing, along the track when approaching the crossing or when stopped at the crossing, hinders drivers' ability to detect an oncoming train and is a critical accident factor at passive grade crossings. Sight restrictions limit the time available for the driver to respond to the grade-crossing situation and affects drivers' ability to judge the speed and distance of an approaching train where cues regarding time and distance are more available with an unrestricted lateral view. Additionally, the site could be physically improved by removing visibility obstructions [1].

Observations of driver looking behavior at grade crossings suggest that drivers do not usually consider sight limitations a problem. Wigglesworth [3] observed driver behavior at one passive grade crossing with limited sight distance at three of the four quadrants. Surprisingly, he found no difference in looking behavior between drivers traveling in either direction.

Some drivers do not realize they are approaching a grade crossing. Driver detection of the grade crossing is difficult at night if it is not illuminated, and physical characteristics of the crossing may limit its visibility. Both these factors delay detection and recognition of trains at or approaching the crossing and may contribute to approximately 10 percent of all crossing accidents [4].

Drivers who are familiar with a crossing have an expectancy about the likelihood of encountering a train at that crossing. If expectancy is low, then the driver who is familiar with the crossing will be less likely to detect a train at that crossing than a driver who is unfamiliar with the crossing or a driver who frequently encounters trains at that crossing [4].

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As the warning time increases, the number of violations also increases. The waiting time was a significant variable in high violation rates at grade crossings [5]. Similarly, in the study [6], the number of violations to the vehicle arresting barrier lights increased as the warning time at the crossing increased. The mean warning time at the crossing was 55 seconds, with an overall range from 26 seconds to 93 seconds. No violations occurred when the waiting times were less than 20 seconds because the barrier nets and gates began to lower within this time interval. However, the number of violations increased by approximately 10–15 percent for every 10 second delay beyond 20 seconds.

Enforcement of grade crossings can occur via one of two methods: a traditional traffic stop, in which a law enforcement officer witnesses a violation and issues a citation to the driver in person; or automated photo enforcement, in which violations are detected via a sensor and captured on film and the appropriate law enforcement authority issues a citation via mail [5].

Public education can inform drivers of the dangers at grade crossings and of the actions required. Rules specifying driver actions at grade crossings vary from state to state, and some states do not even discuss grade crossings in their driver education manuals [7].

2. METHODOLOGY

Focus group surveys or interviews are one way that can be used to gather information on driving behavior at railway crossings. Roy Morgan research [8] surveyed 4,402 drivers and identified the significant role of inattentiveness in increasing rail crossing risks.

Davey et al. [9] made semi structured focused group interviews to 53 young drivers from a regional and metropolitan settings drivers self/reported behaviors, attitudes, and knowledge at railway crossings were explored.

A survey questionnaire that asks motor vehicle drivers' inattentive driving experiences, knowledge, attitudes, and expectations towards safety at railway crossings can be very useful in explaining inattentive driving behaviors. The project [10] investigated motor vehicle drivers' characteristics, their perceptions of safety at crossings, understanding and comprehension of traffic signs/signals at crossings, and their self-reported unsafe maneuvers at railway crossings in many cities of Nebraska. A three-stage mail contact survey design was used. Analysis of the survey responses showed that drivers generally had good knowledge of safely driving at railway crossings.

The approach to this research consists of conducting a field questionnaire survey of drivers in Serbia to collect data on perception of drivers at the local railway crossings.

Tab. 1 presents a list of questions from the survey questionnaire for surveyed drivers that were used to assess the level of safety at railway crossings.

Tab. 1. List of survey questions

No	Questions
1.	I do not trust the signalization at the railway crossing in my city (e.g., flashing lights, half gates, gates, etc.)
2.	I feel unsafe when driving at railway crossings in my city.
3.	I believe that it is necessary to upgrading the level of protection systems at the railway crossing (e.g., flashing lights, half gates, gates, etc.)
4.	I think I have been waiting too long for the train to arrive.
5.	I think that the railway crossing is not well–lit at night.
6.	I think video surveillance at the railway crossing would be useful for upgrading the level of safety.
7.	I think some other advance warning signs would be useful.
8.	I think that sight distances are not well–provided.
9.	I think that crossing surface is not in order due to damage.
10.	I think I know well the railway crossing I use most often.
11.	I have never received information on railway crossing safety.
12.	I support stricter legal regulations related to irregularities in the behavior of drivers at railway crossings.

The survey was conducted at 15 railway crossings, one railway crossing in Kraljevo, Paracin, Batocina and Stepojevac, two railway crossings in Backa Topola and Dimitrovgrad, three railway crossings in Negotin and four in Smederevska Palanka and its surroundings.

The survey was conducted at 15 railway crossings, where, 13 where active railway crossings, one passive and one with a crossing guard. A total of 389 drivers were surveyed.

3. SURVEY RESULTS

Tab. 2 presented a summary of the responses of the twenty single choice questions. A participiant was given a score, from 1 to 5, for each of the above 12 questions. For example, if a driver chose score 1 it means that the respondent "does not agree at all" with the statement in question, that is, if the driver chooses a grade of 5, it means that he "completely agrees" with the statement in question.

For the purposes of analyzing the obtained survey results in the Tab. 3 are summarized score 1 and 2, which mean that the surveyed drivers do not agree with the statement in question. Scores 4 and 5 are also summarized, which means that the surveyed drivers agree with the statement in question. A score 3 means that the surveyed drivers are neutral regarding the statement in question.

Tab. 2. Survey results related to the assessment of the level of safety at railway crossings

Σ surveyed drivers 389		Score				
		1	2	3	4	5
Questions	**1**	144	56	93	46	50
	2	132	70	92	39	56
	3	72	29	63	43	182
	4	42	50	92	55	150
	5	86	35	122	71	75
	6	26	16	47	49	251
	7	70	21	64	60	174
	8	84	49	128	57	71
	9	118	56	86	43	86
	10	11	22	82	79	195
	11	35	18	68	63	205
	12	24	11	57	44	253

To the first question, which refers to the trust in the signalization at the railway crossings processed in the surveys, more than half of the surveyed drivers answered that they have confidence in the signalization that is installed at the given crossings. Drivers in Backa Topola and Smederevska Palanka showed distrust and neutrality in the signalization.

The subjective feeling of safety of crossing the railway crossing was assessed similarly to the first question. Half of the drivers feel safe while crossing the railway crossing. Neutrals and drivers who feel unsafe are again drivers in Backa Topola and Smederevska Palanka.

At 14 out of 15 railway crossings, the surveyed drivers mostly agreed that the level of protection systems at the railway crossings need to upgrading except for drivers in Stepojevac who are satisfied with the level of protection of railway crosing in that place.

The actual warning time provided at a crossing, or the time available between device activation and train arrival, completely agrees with the answers to the fourth question. At railway crossings where the real waiting time is over one minute, drivers feel that they have been waiting too long for the train to arrive. This is particularly expressive at the railway crossings in Negotin, Batocina, Backa Topola and Dimitrovgrad.

The question related to adequate lighting of the railway crossing was assessed as fairly uniform. 38% of drivers stated that railway crossings are not adequately lit, while other drivers are equally neutral or satisfied with the lighting of railway crossings.

Tab. 3. Survey results related to the assessment of the level of safety at railway crossings (in percent %)

Σ surveyed drivers 389		Score		
		Disagree	Neutral	Agree
Questions	**1**	51%	24%	25%
	2	52%	24%	24%
	3	26%	16%	58%
	4	24%	24%	53%
	5	31%	31%	38%
	6	11%	12%	77%
	7	23%	16%	60%
	8	34%	33%	33%
	9	45%	22%	33%
	10	8%	21%	70%
	11	14%	17%	69%
	12	9%	15%	76%

It is interesting that as many as 77% of surveyed drivers answered that video surveillance at railway crossings would be useful due to upgrading the level of safety. This is especially expressive at railway crossings in Negotin, where over 95% of surveyed drivers are in favor of installing video surveillance at railway crossings.

On the seventh question, 60% of the surveyed drivers agree that an additional insurance system would be useful for raising the level of safety at the railway crossing. The exceptions are Kraljevo and Dimitrovgrad, where the surveyed drivers think that the current insurance system is satisfactory.

From the eighth question, it can be seen that at railway crossings where, in addition to road signs, there are also half gates or gates, the sight distances does not greatly affect drivers. Only the surveyed drivers in Negotin, at the railway crossing which is provided only by road signs, stated in large numbers that the sight distances is very important.

45% of respondents said that the crossing surface was in order, 22% were neutral, while 33% of the respondents said that was unsatisfactory. Respondents at the one railway crossing in Negotin and Backa Topola and two railway crossings in Smederevska Palanka spoke in particular about the unsatisfactory situation.

70% of respondents answered that they know well the road crossing they use most often. This is in accordance with the answers of the respondents regarding the frequency of use of railway crossings. Namely, at 11 of the 15 railway crossings, the respondents stated that they use the railway crossing daily or several times a week.

The majority of respondents 69% answered that they have never received information on safety at railway crossings, while 17% are neutral on this issue. This indicates the need for a public educational campaign of road traffic participants regarding the behavior and traffic safety at railway crossings in Serbia. For now, only the campaign on safety at railway crossings is being conducted by the "Serbian Railway Infrastructure" in cooperation with the Media Center "Serbian Railways" among primary school students in Serbia.

Also, the majority of respondents, 76% support stricter legislation related to irregularities in the behavior of drivers at railway crossings. This indicates the fact that the driver's awareness of this issue is present. Unfortunately, it probably occurs as a result of accidents that occur at railway crossings that drivers are informed about through the media.

4. CONCLUSION

Generally it can be concluded that the respondents have a good knowledge of local crossings in terms of the questions in the survey.

More than half of the respondents think that they have been waiting too long for the train to arrive, which is in accordance with the actual waiting times at those railway crossings. This leads us to the conclusion that waiting too long could be one of the causes of distrust in signalization, subjective feeling of insecurity, as well as their assessment that it is necessary to upgrading the level of protection systems at railway crossings.

Also, most respondents answered that video surveillance, as well as some advance warning signs would be useful to upgrading the level of safety at railway crossings.

As we could have assumed, the sight distance of the railway crossing was important to the drivers at the passive railway crossing, while the drivers at the active railway crossings answered that sight distance was not important or they were neutral. This is in accordance with [5]. Namely, the availability of quadrant and track sight distances is less important when concerned with active traffic control; however, the drivers ability to see the train while hi is approaching the crossing may give the drivers more time to contemplate whether to violate or complay and thus, influence the drivers tendency to violate.

Most drivers believe that they have a good knowledge of railway crossings, which was to be expected given their frequent use.

In general, drivers are not satisfied with information on safety at railway crossings, as well as with the existing legislation related to irregularities in the behavior of drivers at railway crossings.

One of the proposals for increasing safety at railway crossings could be to educate the population on behavior at railway crossings. In that education should be included, first of all, driving schools that would spend more hours on this topic, agencies dealing with traffic safety, railways and the media that would point out the behavior of participants at railway crossings to indicate their irregular behavior in order to wake up awareness of traffic participants about the importance of this problem.

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XIX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS RAILCON '20

ENHANCING CAPACITY ON ETCS LINES

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Abstract *– This paper presents the potential increase of capacity on the Austrian high speed line between Vienna and St. Pölten which has been opened in the year 2012 and is operated by ETCS Level 2. Trackside signals are only used as a fall back option. Simulation software OPENTRACK has been applied to calculate headways for different block layouts. Results are presented in this paper and look promising for an increase of capacity on railway lines.*

Keywords – ETCS, headways, simulation, operation

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.

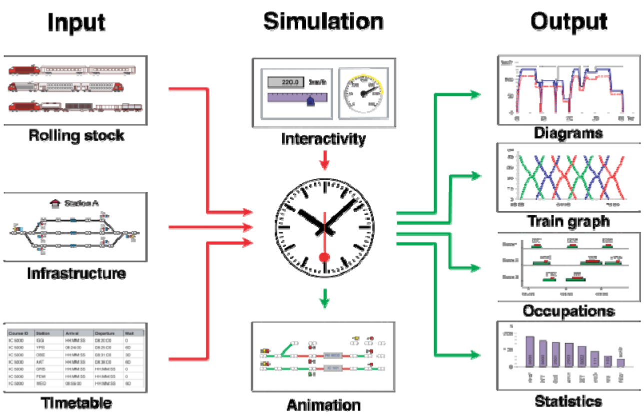

Fig.1. Data flow in OpenTrack

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.

2. SOFTWARE 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 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.

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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).

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. SIMULATION OF ETCS

Regarding the equipment of the lines, ETCS specifications distinguish five application levels: the levels 0, 1, 2, 3 and STM [3]. Level 0 just describes the situation where a vehicle which is equipped with ETCS moves in an unequipped area. Level STM (Specific Transmission Module) is designed for situations where a train which is equipped with ETCS moves on a line without ETCS, but with a national train protection system. This level has been developed for the migration period.

In ETCS Level 1 the main transmission medium are so called Balises which transmit movement authorities and profile data to the train. Balises can be fix data or switchable balises. The former store the data content in the balise itself (only static data), whereas the latter, a Lineside Electronic Unit (LEU) selects the data according to input information (e.g. signal aspects). Besides the balises, linear infill devices can be used locally to transmit changes of signal aspects beyond. These are Euroloops (cable loops in the rail) or radio infill units. Therefore Level 1 provides continuous guidance functions by movement authority.

In ETCS Level 2 and 3 information can be continuously and bidirectionally transmitted by Euroradio, a radio standard based on GSM-R. The central trackside unit is the Radio Block Centre (RBC). In contrast to Level 1 the trains are individually known in the RBC. The train requests new movement authorities in regular time intervals or at particular events. A difference between Level 2 and 3 is that in Level 2 ETCS only takes the responsibility for signal and train protection functions, whereas Level 3 also replaces the interlocking-based track clear detection by continuously checking train completeness on the train and transmitting this information to the RBC.

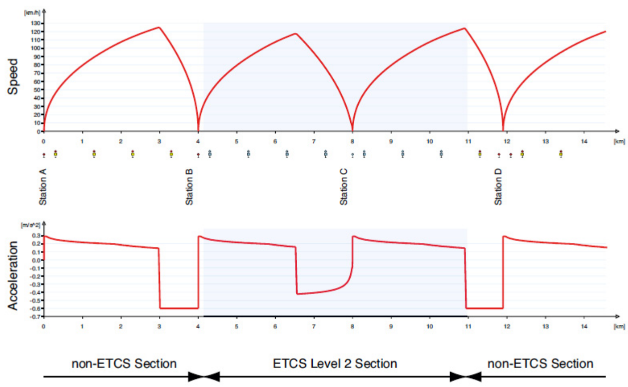


Fig.2. Speed-distance and acceleration-distance diagrams for non-ETCS and ETCS Level 2 sections

The interesting investigation of non ETCS and ETCS Level 2 sections is the behaving of trains in terms of speed and acceleration. Finally the running time is influenced and thereby the timetable has to be modified. The maximum speed achieved by the train is lower and the braking procedure has to start earlier due to reduced deceleration.

4. SHOW CASE IN AUSTRIA

Since 2012 the new high speed line between Vienna and St. Pölten is in operation. The line is designed for speeds up to 250 km/h. Unfortunately, there is no train in Austria available to reach this speed limit. Nevertheless, Austrian Railways use their RailJet services with a speed limit of 230 km/h. RailJet consists out of a Taurus engine and seven trailers. Taurus engines are also used for freight trains with a maximum speed of 100 km/h. For both headway scenarios the headway calculator of OpenTrack has been used to compare headways with ETCS Level 2 vs. ETCS Level 3.

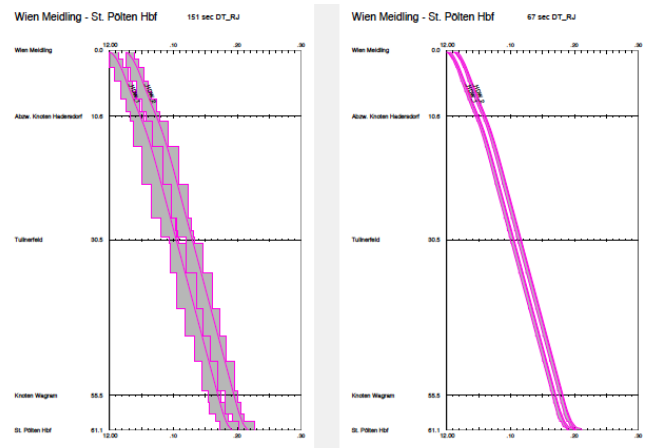
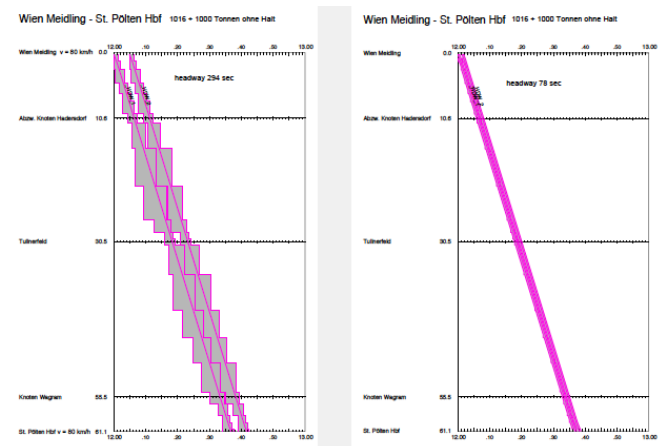


Fig.2. Headway for two RailJets with ETCS Level 2



(left) and 3 (right)

Fig.3. Headway for two Cargo trains with ETCS Level 2 (left) and 3 (right)

Results are promising since ETCS Level 3 would allow to shorten the headway from 151 to 67 seconds for two RailJet services and from 294 to 78 seconds for two cargo trains. During day time this would allow to double the frequency of passenger services. Even more interesting is the possible increase of capacity during night time for cargo trains. ETCS Level 3 with moving block would allow to have almost four times more cargo trains. Of course, ETCS Level 3 is currently not available as a solution on the market but with short blocks in ETCS Level 2 headways can be pretty close to the ones possible in ETCS Level 3. Signals can be only virtual in ETCS Level 2 while axle counters have to be physically placed wayside wherever a short block ends. Results from the headway calculator show that it is a promising topic worth to be investigated as a business case for railway infrastructur managers. Since axle counters are a relatively cheap component of railway infrastructur it should be economically feasible to install them frequently to increase capacity on ETCS Level 2 lines.

5. CONCLUSION

OpenTrack is an efficient and effective railway simulation program. It has been used successfully in many different railway planning projects throughout the world. The program's use of object oriented programming and the RailML data structure makes it particularly effective since the program can be modified relatively easily to address specific applications and since data can be transferred easily to and from other programs based on RailML. Therefore it seems to be highly recommended to apply it also for the evaluation of the operation performance for the planned introduction of ETCS in the network of Croatian Railways. As the Austrian show case has clearly shown an increase of capacity even on high speed lines is possible. Another field of application is the implementation of ETCS Level 2 on existing lines with shorter blocks than in the existing layout.

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XIX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
RAILCON '20

TRAFFIC SAFETY AT LEVEL CROSSINGS

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Abstract *– In order to improve the safety of participants in road and railway traffic, as well as to reduce direct material damage, all the necessary activities should be taken to find solutions to overcome problems at level crossing. Therefore, this paper represents an analysis of transport safety at level crossings. The objective is to point out the dangers arising at level crossings, to analyse the causes of accidents at level crossings, the non-compliance between road and railway regulations regarding securing of level crossings and to propose measures for increasing safety at level crossings.*

Keywords – safety, level crossings, regulations

1. UVOD

The development of traffic and transport is a very important factor in the development of civilization, but in addition to significant advantages, traffic brings a number of problems.

Traffic accidents and accidents are becoming more frequent and burden modern humanity with huge losses in terms of human and material resources.

Locations where the road, as part of the road infrastructure, intersects at the same level with a railway line as part of the railway infrastructure are dangerous and as such cause an increased risk of traffic incidents and accidents. The zone of a level crossing involves intersection of two different modes of transport and from the aspect of traffic safety this represents a collision point for both of these types of transport.

This paper describes the basic inconsistencies between railway and road regulations in the field of traffic safety with reference to laws, rulebooks and regulations.

2. LEVEL CROSSINGS AS SPECIAL SEGMENTS OF RAILWAY INFRASTRUCTURE

The railway network of ”Infrastruktura železnice Srbije” a. d. is more than a hundred years old, and more than 55% of all railway lines were built in the 19th century. The average age of the tracks is about 43 years, of electrical installations between 30 and 40 years, and the length of the tracks on which the maximum permitted train speed has been reduced is also significantly increasing.

Level crossings are the intersections of railways and roads, pedestrian and / or bicycle paths at the level of the tracks and as such they represent critical points of railway lines because this is where most accidents occur with very frequent, fatal consequences.

The common interest of all subjects involved in the management of level crossings is to reduce (remove or provide denivelation) the number of level crossings or to equip them with modern signalling devices with half-barriers and light traffic signs on the road, with the aim of improving traffic safety and reducing the number of traffic accidents.

According to the official data of the “Infrastruktura železnice Srbije“ there are in total 2.138 level crossings on the railway network of the Republic of Serbia and on 3.724,5km of public railway lines.

Out of a total of 2,138 level crossings, 502 level crossings are provided with signal-safety equipment, such as automatic barriers, half-barriers, light and sound traffic signals. Out of 502 level crossings, 25 are provided with light signals and traffic signs, 281 are provided with automatic half-barriers with light signals 281 and 196 are provided with mechanical barriers and traffic signs, while there are only 2 level crossings where traffic is secured by manipulation on the spot.

The remaining 1,636 level crossings are not

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technically secured, i.e. they are provided with vertical signalization (Saint Andrew's cross, Stop sign, visibility zone), but many of them are planned to be technically secured in the near future.

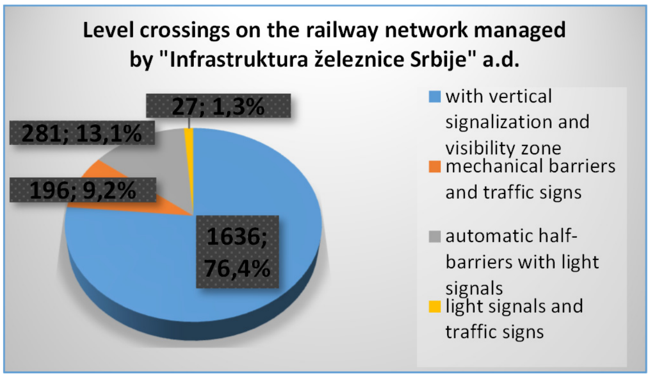

Fig. 1. Level crossings on the railway network managed by "Infrastruktura železnice Srbije"

How, and in what way, a particular level crossing will be secured depends on many things such as visibility on the railway line and road at the intersection (visibility triangle), purpose of the railway line, type of road, traffic density, maximum speed, length of the level crossing and free space above the level crossing.

It should be noted that it is not possible, nor realistically justified, for all level crossings to be secured with automatic devices, and this is influenced by the economic and technological aspects of equipment and maintenance that level crossings require, which means very high investments.

3. TRAFFIC ACCIDENTS AND INCIDENTS ON LEVEL CROSSINGS

The main challenges faced by railway traffic are operational efficiency, increasing reliability, reducing and eliminating delays, increasing the capacity of railways and stations, with a constant obligation to maintain the highest possible level of safety.

On the network of the Republic of Serbia, there are a large number of level crossings that have been opened and put into operation without having previously complied with basic parameters such as the required visibility or distance between level crossings.

All participants in road traffic, cars, trucks, buses, motorcycles, pedestrians, represent a danger to the railways. Each of the participants requires a specific and special study in order to reduce the number of accidents and incidents as well as their causes.

The Rulebook on the Intersection Between Railway Lines and Roads, Types of Crossings, the Place where the Intersection can be Realized and the Measures for Ensuring Safe Traffic at level crossings.

Article 3 of the Rulebook clearly defines the intersection between a railway line and road, pedestrian or bicycle path which can be realized in two ways:

1) outside of the track level,
2) At the track level.

Of all the solutions, taking into account the rules and regulations, it would be best to realize intersection in two levels - denivelation, but such solutions are very expensive. The direct intersection of two different modes of transport is a priori a source of problems and inconsistencies.

The range of circumstances causing accidents and incidents at level crossings is very wide, there is a large number of emergencies with minor or major consequences in the number of casualties and minor or major material damage.

A large number of accidents and incidents at level crossings occur due to the misbehaviour of road vehicle drivers, their disrespect of legal regulations and performance of prohibited actions.

In Figure 2, based on the data provided by the public railway infrastructure manager, shows the ratio of the number of accidents and incidents and the number of people killed in them, which occurred at level crossings on the railway lines in the Republic of Serbia in the period from 2014. to 2019.

- Number of accidents and incidents on public railway lines

2014.	2015.	2016.	2017.	2018.	2019.
564	602	439	598	548	316

- Number of deaths in accidents and incidents

2014.	2015.	2016.	2017.	2018.	2019.
9	3	10	8	14	19

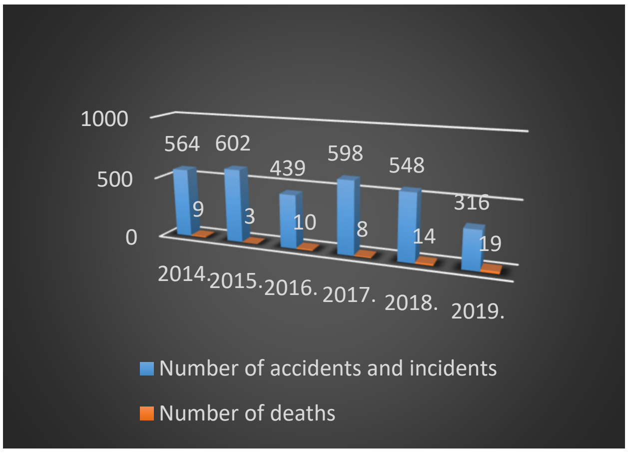

Figure 2. Number of deaths comparing to the total number of accidents and incidents for the period from 2014 to 2019

4. INTERSECTION BETWEEN A RAILWAY LINE AND ROAD

At level crossings, railway traffic always has an advantage over road traffic, regardless of the rank of the road, which is prescribed by the Law on Railways and the Law on Roads.

In the field of railway traffic:

-intersection between a railway line and road is set out by Articles 96 and 97 of the Law on Safety in Railway Traffic. ("Official Gazette of the RS", No 41/2018) and Articles 3, 5 and 10 of the Rulebook on the Intersection Between Railway Lines and Roads, Types of Crossings, the Place where the Intersection can be Realized and the Measures for Ensuring Safe Traffic ("Official Gazette of the RS", No 89/2016),

-appearance, shape, dimensions of half-barriers and traffic lights at level crossings, in Articles 19 and 24 of the Rulebook on the Intersection Between Railway Lines and Roads, Types of Crossings, the Place where the Intersection can be Realized and the Measures for Ensuring Safe Traffic,

-costs of opening and maintenance of level crossings, in Articles 61-70 of the Law on Railways ("Official Gazette of the RS", No 41/2018).

In the field of road traffic:

-Traffic at the road crossing over the railway line and marking of the road crossing over the railway line, in Articles 100, 101 and 153 of the Law on Safety of Road Traffic ("Official Gazette of the RS", No 41/2009, 53/2010, 101/2011, 55/2014, 32/2013 – Decision US RS, 96/2015 – other law, 9/2016 - Decision US RS, 24/2018, 41/2018, 41/2018 – other law and 87/2018.)

-Rulebook provided for by the Article 153, paragraph 5 of the Law on Safety of Road Traffic

-Maintenance of traffic signalisation and equipment and cost of intersection between a public road with the railway infrastructure, in Articles 68, 82 and 83 of the Low on roads ("Official Gazette of the RS", No 41/2018 and 95/2018 – other law)

-Traffic lights, barriers i.e. half-barriers, in Articles 81 and 84 of the Rulebook on Traffic Signalisation ("Official Gazette of the RS", No 85/2017).

4.1. Collisions between road and railway traffic regulations

The discrepancies between the regulations related to intersections between the railway lines and road are the following:

1) Road regulations provide only for two ways of securing the traffic at the intersections between the railway lines and roads – traffic lights and barriers/half-barriers (Art. 101 and 153 of the Law on Safety of Road Traffic), while railway rules provide for six different ways set out by Article 10 of the Rulebook on the Intersection Between Railway Lines and Roads, Types of Crossings, the Place where the Intersection can be Realized and the Measures for Ensuring Safe Traffic,
2) The Law on Safety of Road Traffic stipulates that the crossing of road and railway lines at two levels shall be realized only on highways (article 7, paragraph 1, point 5)), while Article 5, point 1) of the Rulebook on the Intersection Between Railway Lines and Roads, Types of Crossings, the Place where the Intersection can be Realized and the Measures for Ensuring Safe Traffic prescribes that the crossing in two levels is performed at the intersection of a railway line with a highway and motorway.

Discrepancy under 1) occurred by the adoption of the Law on Safety of Road Traffic in 2009. The previous Law on Fundamentals of Road Traffic Safety contained the following provisions:

-"Art. 114, paragraph 3: At the crossing of the road over a railway line at the same level where there is no device for closing the traffic or devices for giving signs announcing the approach of the train, traffic participants can cross the railway line only after making sure that no train or other vehicle moving on rails is approaching on the railway line.

-Marking the crossing of road over railway line - Article 144. At the crossings of the road over a railway line at the same level, in addition to traffic signs from Article 143 of this Law, there are also barriers and half-barriers, i.e. devices for giving signs announcing the approach of the train if required by traffic density or other conditions at the level crossing. The conditions in which the devices referred to in paragraph 1 of this Article must be installed shall be determined by a rule or regulation adopted on the basis of law."

With the above provisions, there was no non-compliance with the then valid railway regulations, nor would there be any non-compliance with the current railway regulations.

Remarks on the provisions related to the crossing of railways and roads as given in the current Law on Safety of Road Traffic are the following:

> inconsistency with the Law on Safety in Railway Traffic and regulations enacted on its basis,

> solutions, 3/4 of all level crossings in the Republic of Serbia were intentionally or accidentally omitted, which made them illegal from the aspect of this law,

> it is not clear whether the obligation to equip (all) level crossings with barriers or half-barriers applies only to newly opened level crossings or also to the existing ones. The Constitution prohibits the retroactive effect of laws and other general acts, except in exceptional cases. There is nothing on that topic in the transitional and final provisions of the Law on Safety of Road Traffic,

> the analysis of the effects of the Law, more precisely the provisions on the installation of barriers or half-barriers, has obviously not been done. The equipment of 1591 level crossings with the appropriate devices requires funds of around 250 million euros,

- Certain provisions of Article 153 of the Law on

Safety of Road Traffic do not make any sense:

- The criterion for setting traffic lights on all level crossings, with modern surface course over a railway line, announcing the approach of the train, is the type of road instead of traffic density (paragraph 2),
- The provisions of paragraph 4 according to which the devices for the installation of barriers or half-barriers must be removed or covered if they are defected or not used. Why install them at all if there is no obligation to use them and maintain them?
- Providing of all level crossings with light signalling, barriers and half-barriers is not rational or necessary from the economic aspect.

Discrepancy under 2) occurred by the adoption of the Rulebook on the Intersection Between Railway Lines and Roads, Types of Crossings, the Place where the Intersection can be Realized and the Measures for Ensuring Safe Traffic in 2016.

This discrepancy can be removed in one of the following ways:

- in the Law on Safety of Road Traffic in Article 7, paragraph 1, point 6) add the following wording: “without intersection at the same level with railway lines“ or
- in the Rulebook on the Intersection Between Railway Lines and Roads, Types of Crossings, the Place where the Intersection can be Realized and the Measures for Ensuring Safe Traffic in Article 5, point 1) erase the wording “and motorway“.

Mistakes found in the Rulebook on the Intersection Between Railway Lines and Roads, Types of Crossings, the Place where the Intersection can be Realized and the Measures for Ensuring Safe Traffic:

- Article 2, point 3) states “railway vehicles“ and it should state “trains“. The mistake is obvious since 75 railway vehicles represent only 2-3 trains, which is a negligible number. Article 5, point 4) states correctly “75 trains on a single-track railway line, i.e. more than 150 trains on a double-track railway line per day on average annually“
- In Article 24, paragraph 3 shall be amended and read: “Appearance, shape, dimensions and installation of barriers and half-barriers on level crossings are prescribed by the Serbian standard SRPS Z.S2.150.” The standard SRPS Z.S2.150 relates only to barriers and half-barriers and not to light traffic signs on level crossings. Those are regulated by the standard SRPS Z.S2.580, which is referred to in Article 19 of the Rulebook.

5. CONCLUSION

The aim of this paper is to point out in a certain way the problems related to accidents and incidents at level crossings in Serbia and to point out the conflict between railway and road laws and regulations. The paper presents discrepancy between the Law on Safety in Railway Traffic and Rulebook on the Intersection Between Railway Lines and Roads, Types of Crossings, the Place where the Intersection can be Realized and the Measures for Ensuring Safe Traffic with the Law on Safety in Road Traffic and Rulebook on Traffic Signalisation with reference to certain Article of these laws and regulations, the observed errors in the Rulebook on the Intersection Between Railway Lines and Roads, Types of Crossings, the Place where the Intersection can be Realized and the Measures for Ensuring Safe Traffic and a proposal to eliminate them.

The common interest of all subjects of level crossing management is to reduce (remove or provide denivelation) the number of level crossings or to equip them with modern signalling devices with half-barriers and light traffic signs on the road, with the aim of improving traffic safety and reducing the number of traffic accidents.

The cause of a large number of accidents and incidents in our country can be attributed to not giving enough importance to this issue. The paper covers only a small part of this broad and complex problem.

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Infrastructure

EVALUATION OF TIMETABLE ROBUSTNESS CONSIDERING BUFFER TIMES' AMOUNT AND DISTRIBUTION

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Abstract *– The timetable is one of the most significant documents. Although nowadays is common to produce timetable by using some of developed sophisticated software, on many networks the timetable is created manually, based on experientially defined principles. Then, it is difficult to assess the values of timetable performance indicators. As one of the most important indicators, timetable robustness has been a subject of a large number of scientific researches in the recent past. In this paper we introduce a model for robustness evaluation based on usual scientific techniques. It considers all buffer times and their distribution over the timetable. As it is not too demanding regarding resources, model enables decision-making in the final timetable development phase.*

Keywords – Timetable, Robustness, Simulation, DEA

1. INTRODUCTION

Recently, many models have been developed for a timetable designing process, as well as software tools. However, in many cases, the timetable is made on the basis of experiential principles, without any optimization. On the other hand, railway infrastructure, even in developed European countries, has become a bottleneck with increasing demand for transportation. Therefore, in recent years, great attention has been paid to assessing the quality of infrastructure utilization, primarily through the assessment of timetable parameters, as one of the most important documents of the railway system.

After the restructuring of the railway system, the timetable process went through changes. Train paths are entered in the timetable on the basis of received paths requests, or on the basis of the assumption of which services will be requested during the timetable period of validity. For services that are not regularly planned, requests are submitted and, accordingly, the so-called *ad hoc* paths are designed, if all conditions are met.

On the other hand, the Infrastructure Manager (IM) and the Railway Undertaking (RU) are bound by a contract, which obliges them to pay penalties in case of non-compliance with the timetable or deviation from it. On the other hand, it is necessary to design such a timetable that will enable the smooth functioning of traffic, while minimizing disturbances in it.

This paper describes a theoretical approach to assess the quality of the developed timetable, in order to enable the identification of its weaknesses and their elimination, but also for the comparison of two or more timetables, from the aspect of robustness.

2. MOTIVATION

The timetable must be designed in a such way that it can withstand the delays and perturbations that may occur, without losing its functionality. In [1], a list of indicators for quality assessment is proposed. It contains the following:

- Infrastructure occupation,
- Timetable feasibility,
- Timetable stability,
- Timetable robustness and
- Timetable recilience.

Robustness is the ability of a timetable to withstand the small delays that occur during its execution. In other words, a more robust timetable can withstand more minor primary delays, in the sense that the transfer of those delays will be minimal or even completely neutralized. In order to enable the robustness of the timetable, it is necessary to implement time reserves within the headways, in order to prevent the transfer of delays from one train

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path to another.

The amount of time reserves that can be implemented in the timetable are not infinite. If we observe a timetable and if we would perform train compression in it, in the manner described in UIC Leaflet 406 [2], the total amount, ie. the sum of available time reserves represents the time from the moment of completion of the last train run in the observed period, to the moment of the beginning of the execution of the next cycle of the observed timetable, reduced by headway time. For a hypothetical one-hour timetable this is shown in Figure 1.

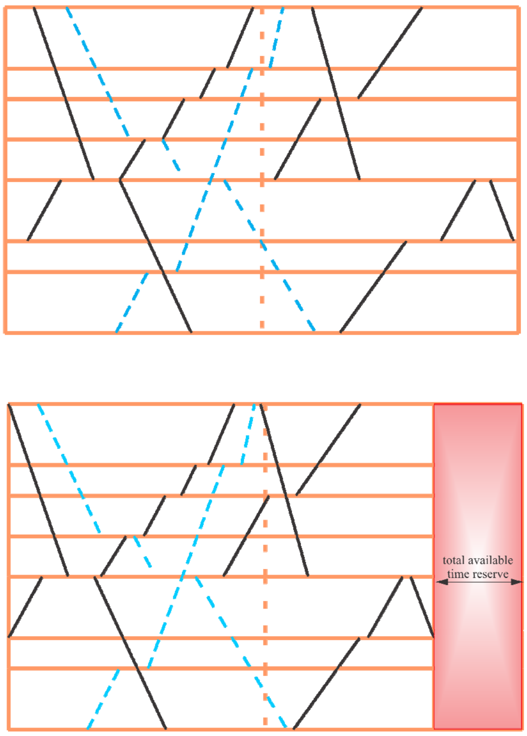

Fig.1. Uncompressed and compressed timetable, with maximum buffer-times amount

From the point of view of robustness, the compressed timetable is not robust at all. Any generated delay would be transferred from one train path to another, due to the absence of time reserves between paths. In practice, this amount of time reserves should be divided into individual buffer times and inserted into headway times.

From the above it follows that the timetable is more robust if the time reserves are more evenly distributed, both in time and space, ie. the maximum robustness would be achieved if the time reserves were completely evenly distributed in each of the stations, as well as throughout the observed time period. A large number of minimum headway times, which are relatively close to each other, will most likely affect one train path multiple times (or even have multiple effects on several train paths), which means a higher probability of transferring delays from a delayed train to another.

Such an ideal distribution of time reserves is not possible in practice, given the required timetable feasibility.

Delays that the implemented time reserves can withstand cannot be determined in advance, given that train delays are random events. Several papers deal in great detail with determining the probability of train delays. Also, in [3], the influence of time reserve distribution on train delays was analyzed, by simulating delays with predefined probability distributions and depending on the adopted mean value of the buffer time.

3. TIMETABLE ROBUSTNESS EVALUATION PROCESS

Since delays depend on many parameters, the timetable realization, determining the distribution of probabilities of delays will not always lead to quality results.

The model assumes that each timetable can be cosidered as a technical system. Then, by simulation, it is possible to determine the values of individual parameters on the basis of which it would be possible to compare timetables, according to efficiency. The block diagram of the model is shown in Figure 2.

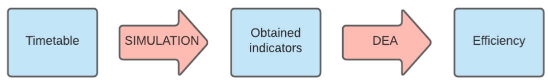

Fig.2. Model Block-diagram

Today's digital computer technology provides the possibility of a relatively easy process of computer simulation of timetable realizations.

If we considered each delay, of each individual event in the timetable, as a random variable, with an identical probability distribution, and if we assume that their expected values and variance are finite, then the central limit theorem would apply to the case of a large number of repetitions. The algorithm of the simulation process is shown in Figure 3.

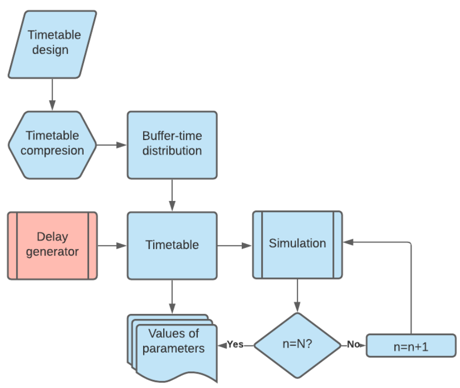

Fig.3. Proposed timetable simulation algorithm

The number of repetitions is not strictly defined; although it is easy with today's computers to repeat the experiment tens of thousands of times, in [3] and [4] the results with acceptable accuracy were obtained with a 500 repetitions.

Statistical indicators, such as the average value of the buffer time, etc., could be determined directly from the timetable, while the expected value of the secondary delays are obtained as the mean values of all repetitions.

The Data Environment Analysis (DEA) method is one of the most commonly used methods for determining the relative efficiency of a set of mutually independent decision units (DMU). In this model, each timetable, with a unique path pattern layout and a unique distribution of time reserves in the headway times between them, as well as the values of each individual buffer time, represents one DMU.

The application of the DEA model for the evaluation of efficiency in the field of railway transport is not new, but it has not been used for the evaluation of the timetable efficiency nor timetable comparation by robustness.

The DEA method involves determining two sets of factors: input and output factors, which represent the basic ratio for determining efficiency.

The set of input factors should be formed on the basis of statistical indicators that can be defined over the timetable in question. These should be such indicators that can be expected to have a significant impact on delays, and thus on the robustness of the timetable. With this in mind, we propose the following indicators for a set of input factors:

- Total number of paths,
- Total number of implemented buffer times,
- Total amount of implemented time reserves,
- Average number of implemented buffer times, per train path,
- Average value of buffer time, per path,
- Average value of one time reserve, etc.

Some of the above indicators are "interdependent", i.e. grouping all indicators into a set of input factors can be redundant. If this happens, it is possible to relax the set of input factors by removing a number of indicators from the set, as described in [5].

With a set of output factors, things are slightly more complex, although the number of indicators - candidates for the output factor, is much smaller. Namely, in order to make a comparison according to robustness between several timetables, it is necessary to observe the sum of all secondary delays. However, the DEA method, in its most general form, is a model for maximizing the ratio of output and input factors, so if the sum of secondary delays is taken directly, those DMUs (timetables) whose secondary delays are higher would be considered as more efficient.

To prevent this, we chose the reciprocal of the sum of the secondary delays as the output factor. It is now possible to use DEA method to compare timetables according to robustness, by defining the relative efficiency of the technical system. The block diagram of the DEA model is shown in Figure 4.

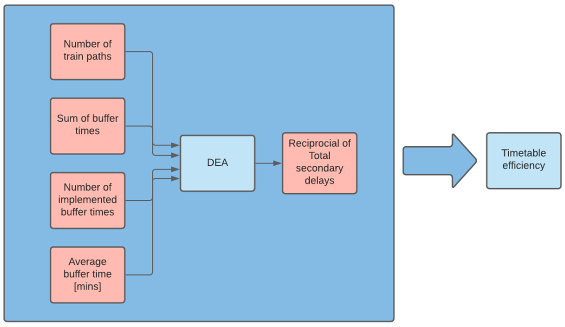

Fig.4. DEA method decision process

The DMU, whose efficiency is equal to one, will be considered the most robust - efficient, while all the others will be considered inefficient. In case of the need to rank all timetables, the so-called super-efficiency DEA method has been used.

4. CONCLUSION

The described two-stage model should allow a simple and easy comparison of timetables based on robustness. The model uses common techniques, simulation and DEA analysis. The model is set up to allow comparison of different timetables, even comparison of timetables for different railway lines, which allows the assessment of the quality of work of timetable constructors or software.

With minimal modifications, practically only with the change of output indicators from the DEA model, the model can also be used to evaluate other timetable performance indicators.

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ELECTRONIC AXLE COUNTER

Dejan LUTOVAC[1]

***Abstract** – This paper describes the Electronic Axle Counter - EAC system. The system is developed, realized and tested in Serbia. It is verified and approved for use on Serbian Railways by the Directorate for Railways of the Republic of Serbia. EAC is a computer system based on the PLC family - HiMatrix, produced by the German company HIMA Paul Hildebrandt GmbH, which has the highest safety integrity level - SIL4 in accordance with European railway standards - CENELEC. EAC is a standardized, modular and scalable system practically independent from the track layout and the country of the application. The operational, functional and traffic requirements and safety principles of an axle counter system are converted to the software of EAC. The track layout dependent data and particular application requirements, are standardized in predefined application cases, which are covered with predefined software modules. Necessituy to create additional software modules for special application cases is reduced, but possible if required. The outputs of the tracks vakancy are available in two forms: as digital outputs dedicated to drive safety relays, or as variables ready to be transmitted via safe-ethernet connection to the Electronic Interlocking system, based on the same PLC family (HiMax and/or HiMatrix). A general disadvantage of axle counters related to the detection of a broken rail is overcomed by optional use of additional hardware modules - Electronic Rail Contacts, which are capable of detecting rail continuity for the distances up to 10km. The described approach allows a fast and efficient realisation of a railway station axle counter system and contribuites to the significant cost reduction of the complete interlocking system. EAC system is produced by Signalling & Control Ltd, Belgrade and approved for use in Serbia by Directorate of Serbian Railways.*

Keywords - Axle counters, railway interlocking system, SIL 4, safety critical software, broken rail detection, availability and maintainability.

1. INTRODUCTION

EAC – Electronic Axle Counter is a computer-based system of the highest level of safety (SIL4 in accordance with European CENELEC railway standards [1], [2], [3]), which is intended for detection of free/occupied state of the controlled track sections in the railway station and in the inter-station area (on the open line with simple inter-station dependency and on the line with automatic blocks), and for the approach and island sections at the level crossings. In the simplified version (wheel detection function, without axle counting function) is used for switching-on and switching-off devices for the level crossings, as well as, for punctual anouncing devices (80 meters contacts and similar) and a route release after overlap section after signal is released.

2. PURPOSE AND MARKET

EAC is realized as a modular and scalable system that can be used for a variety of safety (the counting function and duplication in the aim of achieving safety) and the non-vital (wheel detection, single and double application to increase availability) applications, depending on the track configuration in different railway authorities. EAC is an economical system that is highly competitive to both, computer-based and conventional relay systems, which are used for the specified purpose.

EAC is developed and realized on the bases of world wide experience and know how of Serbian engineers.

3. EAC HARDWARE ARCHITECTURE

EAC is realized as a modular and scalable system, which can cover all types of various stations track configurations and signaling arrangements, from simple (small) to very complex (large), for various country practices and various railway authorities.

An example of EAC architecture is presented in Figure 1.

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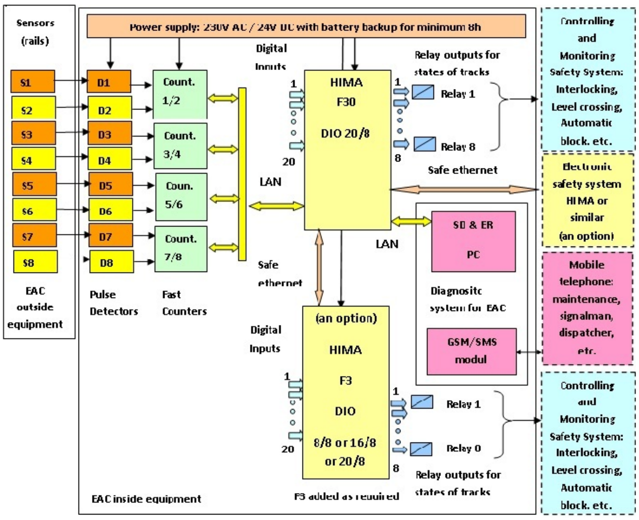

Fig.1. EAC - Architecture example

EAC system contains the following main parts:

- Outside equipment, as shown on Figure 2:
  - wheel sensors for detection of wheels, i.e. axels, connected to the inside equipment via the trackside connection box containing overvoltage protection modules.

Fig. 2. EAC Outside Equipment

- Inside equipment, as shown in Figure 3:
  - Power supply - Rectifier, UPS, batteries, DC/DC converters and fuses for all necessary internal and external voltages.
  - Central safety controlling system (SIL4) realized with HIMA PLC family HiMatrix (for small and middle range, independent applications) or HiMax (for larger applications and inside the EI - Electronic Interlocking system produced by Signalling & Control Ltd) [4].
  - Pulse detectors for detection of wheels from the wheel sensors.
  - Fast counters for counting the pulses received by pulse detectors from sensors.
  - Miniature safety relays for the outputs.
  - LPM - lighting protection modules with disconnection terminals for connections of outside and inside equipment via cables.

Fig. 3. EAC Inside Equipment.

4. SAFETY OF EAC

Safety of EAC is based on safety Programmable Logic Controllers - PLC of HIMA (HIMA Paul Hildebrandt GmbH + Co KG, Germany), types: HiMatrix F30 (CPU - central process unit) and F3 (DI/O - digital input-outputs) [5], [6]. They are certified for the highest safety integrity level, SIL4, in accordance with European CENELEC railway standards [7].

The block diagram of the architecture of the safety PLC HiMatrix F30 is shown in Figure 4.

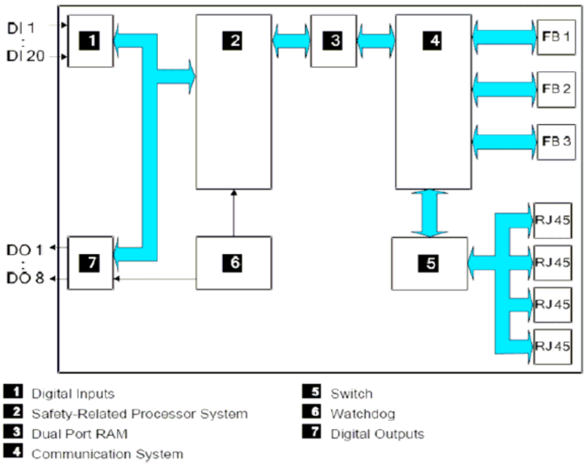

Fig.4. The architecture of HiMatrix F30

Each safety module individually is realized in the safety architecture "2 out of 2", as shown on Figure 5.

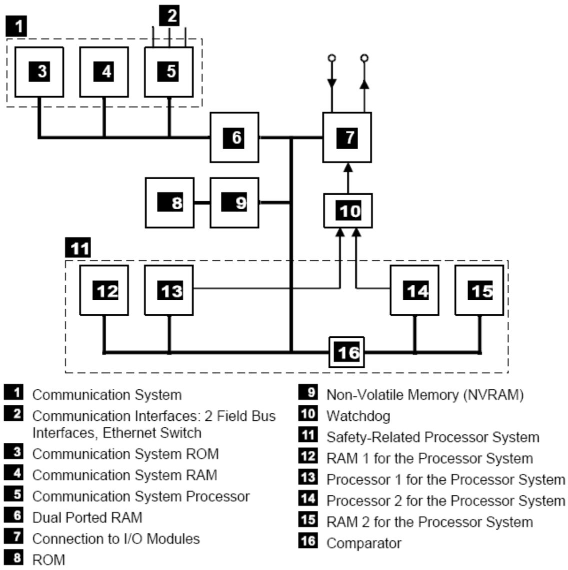

Fig.5. Safety structure of EAC safety modules

5. COMMUNICATION

The communication is vital and duplicated (as required) for the availability. Each external communication channel is realized as a Safe-Ethernet as presented in Figure 6 (vital communication):

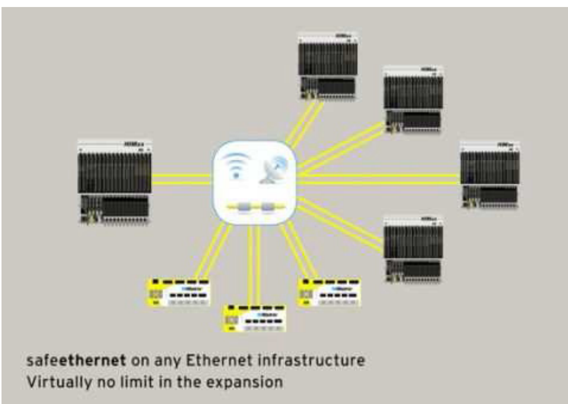

Fig.6. An example of Safe-Ethernet architecture

- within EAC PLC (HiMatrix or HiMax, depending on the size of an application);
- between HiMax PLC (EI - Electronic Interlocking system) and EAC PLC

6. TYPICAL APPLICATIONS OF EAC

EAC is realized as a modular and scalable system that can be used for different applications that require detection of railway vehicle presence on a controlled part of the railway track (instead of a conventional track sections separated by insulated joints).

Typical application of the EAC for the detection of free / occupied state of the track section (instead of the conventional insulated section) is shown in Figure 7.

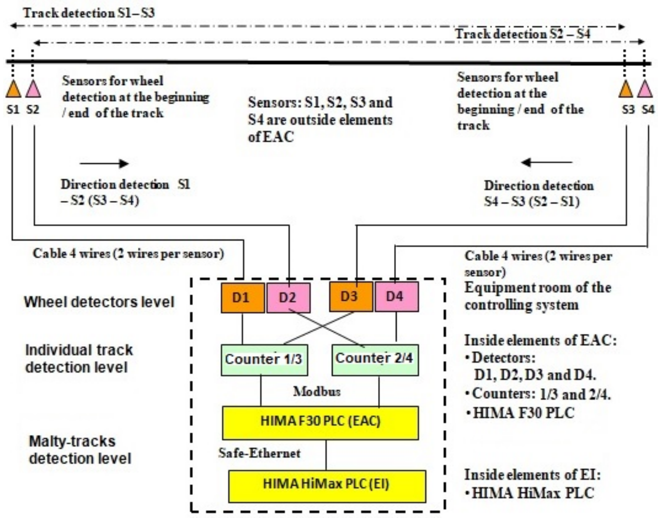

Fig. 7. EAC - Axle counter track - detection of free / occupied track section

A pair of sensors S1 and S3 are mounted at one end, and a pair of sensors S3 and S4 on the other end of the track section that is controlled. Sensors are detecting the wheel (axles) of railway vehicles that cross them. Each wheel pasing over a sensor causes a sensor signal change (an impulse signal is generated) that detects adjusted detector. The first detected impulse also indicates the occupancy of the section.

Sensors S1 and S3, and also S2 and S4, are placed next to each other on short distance that is sufficient for the controlling system to detect the order of occupation of the sensors, i.e. to detect the direction of travel of the railway vehicle. Detectors transmit the received impulse signals futher to the fast impulse counter, which calculates the total number of impulses, i.e. the total number of wheels (i.e. axels) that went over the sensors. Each fast counter transmits the total number of axles that has passed over the sensor to the central safety PLC device HIMA F30.

The safety PLC proceses obtained information for all sensors and track sections and generates the appropriate exits (track section ocupacy and the direction of movement).

The exit deactivates/activates the appropriate miniature safety relay, which by its contacts tranmits the data further to the Central Control and Monitoring Safety system (station interlocking, level crossing controller, block controller, or similar).

The safety PLC of the EAC compares the total numbers of axles from all sensors involved in one track section and on the basis of majority logic makes decisions about their correct functionality or malfunctions. When it finds that the total number of axles entered into the track section is the same as the number of axle that have left the section, safety PLC generates the appropriate exit signals (release of the track section and the direction of movement).

The principle described for one track section applies accordingly to multiple-section configurations. The tracks configuration defines the number and geometry of the rack sections that have to be controlled. For the points track sections, there is one beginning and two ends, so the track is defined with three pairs of sensors and the relevant end of the section is defined by the position of the points.

In cases where it is necessary to control the continuity of the rails in the axle counting track section (like on the one long inter-station track), the low frequency electronic track circuit can be added (version of ERC - Electronic Rail Contact, produced by Signalling & Control Ltd, with low frequency trackside module and appropriate detector).

The typical application of EAC for realisation of the approach and island track sections of the automatic level crossing controller on an open, single line, rail track with bi-directional traffic, is shown in Figure 8.

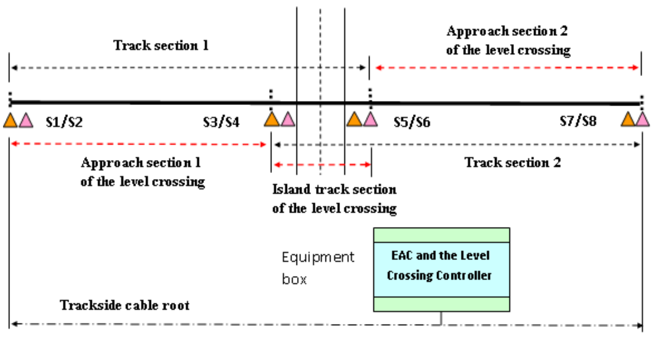

Fig.8. Level crossing with Axle counting tracks

For the switching-on and switching-off of the level crossings controller, two overlapped track sections (Track section 1 and Track section 2) can be used, so their overlap section forms the island section (switching-off section) of the level crossing. The level crossing gets activated by occupation of Approach section 1 on the side of sensors S1/S3 and deactivated by release of the Island section, i.e. passing over sensors S5/S6. Also, the level crossing gets activated from the opposite side by occupation of the Approach section 2, i.e. by occupation of section starting by sensors S7-S8, and deactivates by the release of Track section 2, i.e. release of the Island section passing over the sensors S3/S4.

The EAC, which is located in the Level Crossing House, obtains all necessary data for the Track sections 1 and 2 (free/occupied and the direction of travel) and submits them to the Level Crossing Controller, which provides automatic activation and deactivation of the level crossing.

Depending on the required level of safety of the switching-on and switching-off devices, and the type of the level crossing application, different EAC configurations, or simplified configurations with wheel detectors only, can be used. Depending on the track configuration, type of the level crossing and technical and safety requirements for the application, single sensors or a pair of sensor (duplication for safety or duplication for availability) can be used.

7. CONCLUSION

The described EAC system allows a fast and efficient realisation of the train detection in the railway stations and lines between stations, for the interlocking, block and level crossing applications and contribuites to the significant cost reduction of the complete signalling system.

Directorate for Railways of the Republic of Serbia issued the permanent approval for use of the EAC with rails continuity detection, on Serbian Railways, I-01-1 No.: 340-22-3/2016, from 14.04.2016.y.

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XIX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
RAILCON '20

ESTIMATION OF RAILWAY BELGRADE RING OPTIC NETWORK USING NETWORK PLANNING TOOL

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Dragan JEVTIĆ[2]
Milesa SREĆKOVIĆ[3]
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Abstract *– The communication networks in railway environment demand quick adjustments and flexible approach to end user needs. This requires previous check-up of fallout scenarios' in networks prone to vulnerabilities. Currently evolving communication network (particularly the Belgrade ring) is an interesting case, whose implementation will go through phases. The availability of completed phases would be compromised in case of cable failure, not being an isolated case in practice. The use of software could make some of the fallout scenarios a bit clearer and thus the expected consequences less devastating, making the maintenance teams more prepared. This paper uses one of the open source free network planning tools (net2plan) for such estimation. Since only a few of the spans of interest have been equipped with fiber-optic cables the number of phases of cable routing combinations is significant. However, some are more likely to be laid out earlier, so certain estimations are made in order to further study these scenarios.*

Keywords – fiber optic network, Belgrade ring, net2plan tool

1. INTRODUCTION

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Number of railway lines originating from Belgrade are numerous. Belgrade as a substructure in a greater network is complex. The ongoing projects of development and reconstruction of railway lines mostly incorporates the layout of fiber optic cables for the future optic network. These projects related to permits are geographically bound and even though there are some guidelines for the mutual order of completion various field conditions often render this order useless as projects expected later are finished earlier and vice versa. The Belgrade ring is chosen because of a number of higher order nodes in the ring and a great number of branches (lines, traffic, ..), thus beeing a good representative of the possible problems in the overall network. From the known ongoing projects (designs) it is possible to have some idea of this order of completion, using some of the assumptions. Further in this paper line will represent the railway line we acknowledged, which could be part of one or several official railway lines in Serbian railway network, and the lengths used in model will be actual lengths along the line between nodes according to as – build layout plans. In all fibre spans in ongoing designs railway is planning also a tube with G.655 fibers [1]. The fig 1. shows the order of completion of the railway spans of interest. One line is already equipped with fiber optic cables – Belgrade center (BG.C.)– Karadjordje's park - Pancevo Bridge– Ovca – Pancevo (PA). This line further travels to Vrsac (VR), and that part of the line is not equipped but for this estimation, we assume it is. Second line that was taken into account is the ongoing project Belgrade center (BG.C.)– New Belgrade– Zemun (ZE) – Batajnica (BA) – Novi Sad (NS). This line is branching in Indjija towards SID (shown in fig.1). Third line is the part of Belgrade ring with numerous important points Belgrade center – junction G – Rakovica (RA) – Resnik (RE) and two

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interconnections form Rakovica and Resnik to Belgrade Marshalling Yard (BG.M.Y.). The major national railway lines travel further form this nodes – South 1 (S1: Lapovo – Nis) from Resnik, South 2 (S2: Mala Krsna – Velika Plana – connection to S1), and a line towards Bar (i.e. Valjevo – Pozega – Podgorica – Bar). Fourth line is the western part of the Belgrade ring and it incorporates Belgrade Marshalling Yard – Ostruznica - Surcin – Batajnica (BA). This part of the BG ring is used mostly for freight and as this traffic increases will gain in its significance. Some of the mentioned locations are not nodes in this estimated networks, they mainly serve to give the better understanding of the true line topology.

Fifth and sixth line currently not exist nor are they part of the ongoing projects but are a reality. Studying the map of Belgrade these two lines look highly probable. Fifth line Resnik –Vinca- Pancevo could be realised only through the major national project, being a line that needs the bridge over Danube, as well as a sixth line Pancevo -Batajnica (the interconnecting stations are not noted because there are no reference to relate to).

The future existence of these two lines and the order of their completion are few of the major assumptions in this paper. Node Belgrade Nemanjina, being the administrative center of Serbian railways is not shown in fig.1. Belgrade Nemanjina is currently connected to Belgrade center with fiber optic cable, with no possibility of forming a metropolitan subring, entirely within railway infrastructure. This node will not be included in this estimation.

There is no General plan in force for the finalized railway communication network so the capacities i.e. traffic matrix of all level nodes will have to be estimated, too. This is a main reason why the fig.1 contains information not only about the nodes in the ring but about the further going main railway lines giving thus the information about the future significance of the lines.

One of the intricacies of the railway network are flat rings and rings on the railway line formed using fiber optic on the opposite sides of the tracks. Double-sided fiber links are good practice on lines where ETCS Level 2 (European Train Control System – part of the European Railway Traffic Management System i.e. ERTMS) systems are designed. WDM systems are part of the ongoing designs and IP traffic leaning on WDM are expected throughout the departments [2].

ZE, BG.M.Y and BG.C. are nodes with a significance in the BG ring since it is a reality that in Belgrade most of the control, maintenance and surveillance centers will be places. It is also easier to make one of these nodes a disaster recovery center (BG.C. not a likely candidate because of the shortage of space).

2. MODEL AND THE NETWORK DESIGN OF THE BELGRADE RING IN NET2PLAN

Model and network design of the Belgrade ring are established using certain assumptions and the free

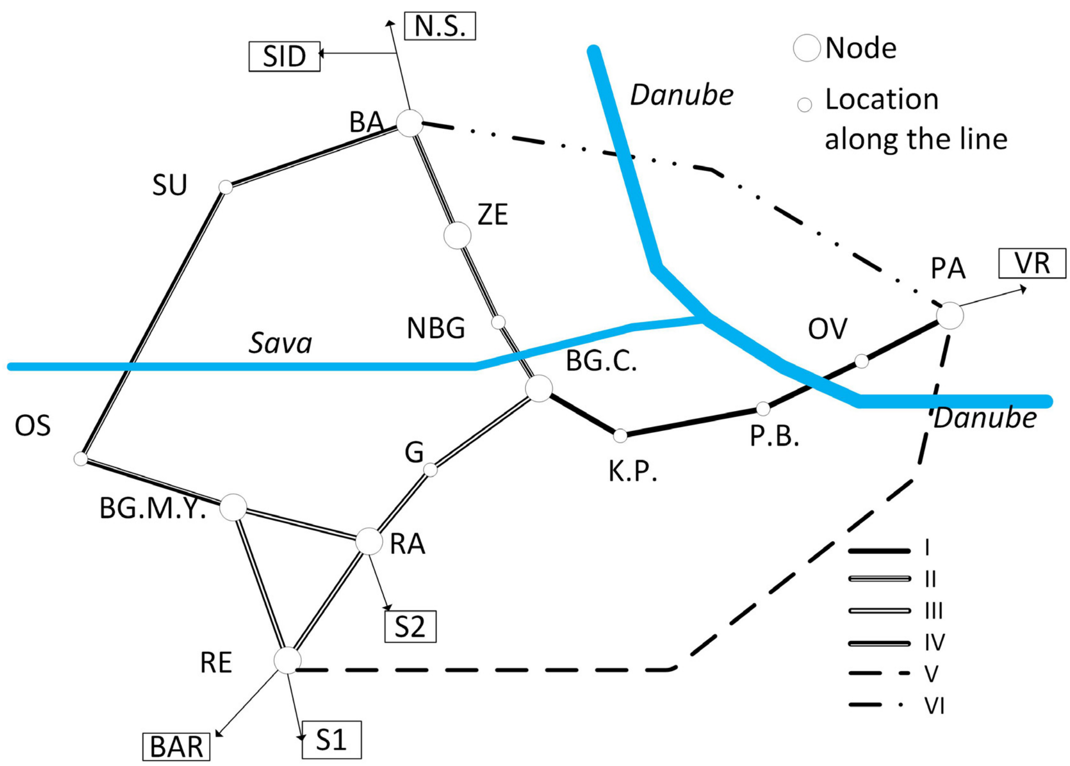

Fig.1. Belgrade ring, lines in it and its nodes relevant to this estimation.

Net2Plan open-source multilayer network planned and simulator (free Java tool) software version 0.6.6.0 [3].

Net2plan delivers reports according to set model. The objects crucial to model are: nodes, links (belonging to different layers), traffic demands, multicast traffic demands, multicast trees, routing of unicast traffic, resources, shared-risk groups.

Communication networks are organized into layers, defined by protocols and departments. The upper layers are connected trough optical connections of fixed capacity in the software i.e. lightpaths, representing direct links (making them the path of optical fiber in the underlying layers along the route). Lightpaths are assigned wavelength, not changing along the route (uni/bidirectional channels). Optical Add/Drop Multiplexers (OADMs) are forwarding lightpaths thus being the optical switching nodes. The network layers are: link, demand, route, forwarding rules, multicast demand and multicast tree. Nodes, resources and shared – risk groups are not assigned to any particular layer [4].

Since this paper deals with the fiber network there are no real demands on the upper layers (i.e. IP layer). So the fig.2 shows only links on the WDM layer, and the IP layer is off. (fig 2. is in correspondence to fig.1). The lines with fibers along both sides of the tracks are chosen to be BG.C. – BA and BG.C. – RA-RE as these lines will be ETCS L2 lines.

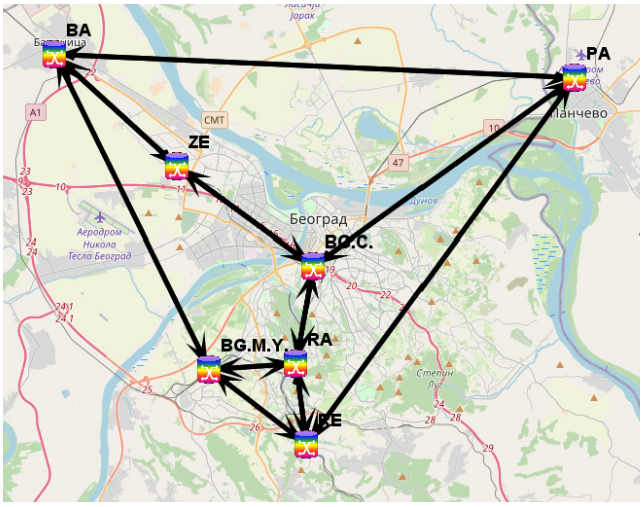

Fig.2. WDM layer

The distances in the BG ring are not lengths that need line amplifiers. Distances on railway lines (SID, NS, BAR, S1, S2) are greater but these lines going further from BG ring, are here mentioned only to avoid BG ring to look like an island in the overall railway network as well as to point out the complexity of the BG ring exit nodes (BA, PA, RA, RE) in terms of installed equipment.

Model envisages the use of generic OADMs and their parameters offered by software. The used WDM range is 193.1 – 197.09 THz (~4THz) with the distance of 12.5GHz [5]. Directionful Add/Drop modules with passive mux/demux elements are with losses of 0.6dB and PDM with 0.5 ps/√km (polarization mode dispersion). Chromatic dispersion CD is set to 15 ps/(nm·km). Attenuation is set to 0.25dB/km. The chosen architecture (terms used in Net2Plan user manuals and documentation) is *broadcast-and –select*. Some of the nodes are particularly complex with 3-5 lines originating from them. This will not be commented further in this paper since those issues must be addressed during real designs and implementation.

On the WDM layer chosen lightpath requests are symmetrical and are a complete mash (all to all) thus giving the bidirectional lightpath request between all nodes with preset line rate 100Gbps and 1+1 protection. Lightpaths are set to be with shortest path in optical latency.

Fibre fallout scenario that was the aim of this paper is basically a sequence of fibre disconnections resulting in the critical network state. There are two approaches that we recognize. First is a state in which not all lines are finished so a full connection state of the nodes is not achieved. The other is if the full network is in work but the main lines are falling out. This means the fibre (link) between adjacent nodes is disconnected (bidirectional fiber link).

3. REPORTS AND RESULTS

Using the *ReportNiw_wdm_routingSpectrumAnd ModulationAssignments* report summary of spectrum occupation information are achieved. Report shows routing and spectrum occupation of the lightpaths in the network. Namely the report indicates the use of 28 fibers, 42 lightpaths (and additional 42 for 1+1 protection). Shown as min/average/max there are 5/32.18/89.25 lightpaths in km and 1/1.9/3 lightpaths in num hops.

Another report is generated in the GUI of the Net2Plan - *ReportNiw_wdm_lineEngineering*. This report shows line engineering information for WDM links in the network. This report generates basic checks for each link and lightpaths (signal power levels, chromatic dispersion, OSNR,..).

With the previously mentioned default values set in the Net2Plan the attenuation on all links (fiber - node to node) has not exceeded 12dB. The net CD is 675 ps/nm for the longest line in model (RE-PA and vice versa). The line with significant CD are also lines BA-PA (525ps/nm) and BG.M.Y. – BA (450ps/nm). This is expected. *Lightpaths* subtab shows no crashing is evident (the bidirectional lightpaths occupy same slots). Signal metric at the transponder show Rx power that is too low for all lightpaths (mandatory range is -20÷10dBm, which is a consequence of passive elements attenuation. This is fixed with a number of amplifiers inserted to compensate this attenuation of passive elements within OADMs.

These amplifiers – boosters and preamplifiers are added into *Fibers* tab. The gain of these initial and end node amplifiers are set to have gain of 15dB for boosters and preamplifiers are set to have gain of 20dB to achieve levels within the sensitivity range at the Rx side. This have stabilized the levels so a report was further clear of unsolved issues.

The fiber network fallout scenario commented in this paper is as mentioned in table 1 (second approach). The table gives the studied disconnections of fibers in BG ring. The table does not treat all fibre links on a line but instead represent only one fibre link in a line and if possible middle one. If there are two fibre links than the link closer to BG.C. is chosen.

*Tab. 1. Fallout scenario for fibre network. If the indicated lightpaths are backups the mark (**b**) is used.*

No.	**Fibre out (bidirectional)**	**Lightpaths (bidirectional) out (backups/not)**
1.	ZE – BG.C. (one side of the tracks)	ZE-BG.C. (**b**), BG.M.Y.-BG.C. (**b**), BG.C-PA (**b**)
2.	ZE – BG.C. (both sides of the tracks)	BA-BG.C, BA-RA (**b**), BA-PA (**b**), ZE-BG.C, ZE-BG.C(**b**), ZE-RA, ZE-BG.M.Y (**b**), ZE-RE, ZE-PA, BG.C-BG.M.Y(**b**), BG.C.-PA (**b**)
3.	ZE – BG.C. and BG.C. – RA (one side of the tracks)	BA-RA (**b**), ZE-BG.C. (**b**), ZE-BG.M.Y(**b**), BG.C.-BG.M.Y(**b**), BG.C. -RA(**b**), BG.C.-PA(**b**), RA –PA
4.	BG.C. – RA (both sides of the tracks)	BA-RA (**b**), ZE-RA, ZE – BG.M.Y (**b**), ZE-RE, BG.C-BG.M.Y, BG.C. – R, BG.C-RA(**b**), BG.C-RE, RA-PA

4. CONCLUSION

The Net2Plan offered enough options to confirm or discard presumption used for this model. The used values and setting are generic enough to assume the given results cover majority of vendors (WDM, fibers). The good railway practice related to double sided fiber line layouts is resilient enough which is shown in the results. This combined with the 1+1 protection is enough for the BG ring to survive chosen fallouts. On both lines that carry the most of the railway and communication traffic BA-BG.C. and BG.C. – RA-RE disconnection of fibers on only one side of the tracks results also in a still functioning network.

It would be beneficial to compare these results to proprietary software of different vendors with real parameters of WDM equipment and fiber optic cables.

Comparison to results of the first approach to fallout fibre network scenario could point out some weak spots in the design also. Thus a more accurate state of unfinished network could be shown with more recognized steps in implementation. These results also point out a necessity for a General plan of complete fiber optic network with appropriate traffic matrices for different demands / departments / subsystems in railway communication network.

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XIX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
RAILCON '20

CABLEWAYS AND RAILWAYS – ECOLOGICAL ASPECTS

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Abstract *– The great external influences of traffic and transport (pollution of water, air, soil, visual intrusion, congestion, etc.) coming from commercial modes of transport, have led to a growing interest in environmentally friendly modes, such as railways and cableways. The goal of their implementation in the daily transport of goods and passengers is to reduce the impact on the environment, health and quality of life of people. The attention of the designers of modern means of transport, in addition to speed, comfort and safety, is directed towards the rationalization of consumption, development and application of systems that ensure the return of part of the invested energy. The concept of sustainable development, which is based on the principles of economic development, environmental protection and the social factor, aims to protect the living resources that we are depleting, which are necessary for future generations. The aim of this paper is to present in more detail the positive impacts of cableways and rail transport as well as the concept of sustainable development.*

Keywords - cableways, railways, sustainable development, environment

1. INTRODUCTION

Preservation of the environment and its protection from further degradation has become a priority, especially since the last decade of the 20th century. The fast development of a number of new technologies has significantly affected the degradation of the environment. On the other hand, transport has become part of the everyday needs of modern man and the phenomenon of mobility has been transformed into a life style [1]. However, since transport more or less damages the environment, the processes of integration of the traffic flows together with changed in the economy and society followed by growing scientific and technological development require a completely new business philosophy and strategy for development of environmentally friendly modes of transport such as railway and special subsystem of passenger transport which includes cableways. The aim of this paper is to represent positive impacts of rail transport and cableways from the point of view of preservation of the environment, as well as a concept of their sustainable development.

2. TRANSPORT AND CONCEPT OF SUSTAINABLE DEVELOPMENT

Nowadays the concept of sustainable development is associated with different activities both in production and provision of services and in the way of life. The concept of sustainable development considers and links economic justification, social factor and environment-friendliness.

Transport that is accessible to all, environmentally friendly and that positively contributes to local, national and international development and sustainable transport. All transport modes pollute the land, water and air to a certain extent. The dominance of road transport as the key land transport mode has shown a number of weaknesses, primarily due to the pollution of air and noise it produces, as well as traffic congestion in cities [1].

The concept of sustainability or sustainable development represents one of the basic concepts of economics of natural resources and the environment. It implies the need to balance various social values and the real pace of development of the society and thus provide a long-term perspective of the survival and progress of humanity. Therefore, sustainability means harmonization of the economic growth and development of the society with mandatory protection of the environment. Indicators for monitoring of the sustainability concept are based on modern environmental laws which aim to reveal the causal links between economic policy and policy of

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protection and improvement of the environment. [1]

Indicators of sustainable development indicate where the causal links between the economy, environment and society are becoming weak and show a way to solve these problems. A reliably indicator warns about a problem before it becomes serious and helps us understand what should be done in order to solve that problem. Indicators are as various as the types of systems they monitor, but there are some characteristics that are common to all efficient indicators. They are relevant, easy to understand, reliable and based on available data. One of the biggest problems in developing indicators of sustainable development is that often the most needed indicators are those for which there are no data, while indicators for which data are available are the least suitable for measuring sustainability. Therefore there are several advantages of traditional indicators:

- Data are easily accessible and can be used for comparisons at the national and international level;
- They help to define difficult areas;
- They can be combined in order to develop indicators of sustainable development [2].

Some indicators of sustainable development have acquired the same level of support as traditional economic indicators and thus proved to be a useful tool for improvement of sustainable development. So far, no method for determining qualitative indicators of sustainable development has gained a level of general acceptance. Therefore, states, professional and scientific institutions in different areas are making huge efforts to develop indicators of sustainable development [2]. The foundations on which sustainable future of modern society should be based consist of three dimensions: economic, environmental and social sustainability.

A fourth dimension is accepted in literature – cultural sustainability [3].

3. CABLEWAYS AND ELEMENTS OF SUSTAINABLE DEVELOPMENT OF CABLEWAYS

Population mobility has always been important in the context of socio-economic and technical-technological point of view. However, there is a growing importance of the environmental aspect of sustainable development. The main case of technical-technological aspects can be seen in motorized vehicles, where, thanks to emission standards, the damage of exhaust gasses in the environment and harmful impact on the health of the population is reduced. Buses, tramways, trolleybuses, cars and recently electric cars are already widely used in cities. However, the problem of today's mobility in the city is that it takes place mostly at ground level and as a result streets and city roads are very busy, which leads to more frequent and increasing congestions. Cableways could have an important role in solving of this problem [4].

Cableways represent a subsystem of public transport of passengers where transport of passengers is realized by fixed routes on which cabins fixed on one or more cables are moving, while the power system during the whole period of functioning uses the electric energy [5]. At the moment cableways are mostly used for touristic purposes, the most often in ski centres and much less in urban centres. In urban areas they are mostly used for transport of passengers to locations that are at higher altitudes and at short distances. Suspended cableways have a great potential for use in urban areas. Their work can greatly contribute to relieving the traffic in cities, but the problem is that they do not have the necessary capacity to transport passengers, since their maximum capacity is 4.000 passengers / h. Therefore, they are not competitive with other subsystems for passenger transport in urban centres. However, in some cities such as Medeljin, New York, London, Portland, Caracas, Rio de Janeiro and La Paz, they are widely used as a subsystem of public transport of passengers and they have greatly contributed to relieve the city roads [4]. Figure 1 shows a cableway in London called: "Emirates Air Line" which transports passengers across the river Thames to the sports hall O2. At the highest point, the passengers are at about 90 meters above the surface of the Thames and the total distance crossed by each of the gondolas is 1.100 meters. The journey takes five to ten minutes and sometimes even longer so that the tourists can enjoy the view of London from the gondolas. Besides being a real decoration, the gondolas gliding at about 50 meters from the water are also a key transport across the river Thames to East London and one of the attempts to renew the local economy [6].

Fig. 1. Cableway in London [5]

Cableways as a subsystem of public transport of passengers have a number of advantages from the aspect of preservation of the environment comparing to other modes of transport: use of electric energy which can be obtained from renewable natural sources, no emission of CO2 and exhaust gases, much less emission of noise, etc.

Thanks to the above mentioned advantages, transport of passengers by cableways can become competitive with other modes of transport in urban areas. In order to achieve that, it is necessary for cableways to increase their capacitiy, i.e. to transport a larger number of passengers per hour. One of the possibilities is to reduce the intervals and distances between cabins, which can be achieved by additional platforms and thus increas the capacity [6].

When we talk about the elements of sustainable development of cableways, we observe specific environmental, economic and social paremeters characteristic for cableways.

Environmental parameters of cableways are observed through the consumtion of resources of water for making artificial snow, then through erosion of the ground due to the use of ski centres, parameters of destruction of certain species of birds and plants in the area where a cableway is used, as well as one of the most important parameters – impact of the construction of cableway on the environment.

Economic parameters are the duration of the ski season, number of skiers, number of passengers using the city cableway and earnings, where the objective is to achieve the maximum values of these parameters.

The social parameter is the fact that spending time in nature has a positive impact on people's health, socializing, playing sports and that as a final result we have a healthy and satisfied user.

From all the above we see that it is complicated to harmonize all these pareameters because an increase of one parameters results in a decrease of another.

4. ENVIRONMENTAL ASPECT OF RAILWAY TRANSPORT

The quality of railway traffic and transport can be seen as a level of user satisfaction, increased protection of the environment and safety in transport. If we take into account energy efficiency and quality, railways meets the criteria of the most convenient transporter. The ecological risk caused by railway traffic is the most often manifested in three forms, namely: impact on the environment, safety of transport of poisonous, inflammable and explosive goods, impact on employees and passengers [7]. Thanks to the growth of environmental awareness and implementation of environmental laws, the railway system, as the system with the highest capacity, the least air and water pollution and the least use of land, represents an important competitor to other modes of transport. In 2011, the European Union presented a number of objectives for establishment of a competitive and efficient transport system, which should be realized by 2050. The main goal is to reduce the emission of gases, which contribute to the creation of the greenhouse effect. Moreover, the plan envisages the development and application of new sustainable drive systems and fuels [8].

The railway system has a very important role in reduction of negative impacts of traffic on the environment through management of energy-related emission and ensuring a continuous supply. A positive impact comes also from efficient use of available resources. Railways play an important role in minimizing the environmental effect of transport. As mentioned, the railways uses electricity as a fuel with a great work performance (it transports passengers and goods). In order for the numerous environmental advantages of railways to be visible, it is necessary to manage the railway traffic well and efficiently. Otherwise, the quality of the environment may be significantly deteriorated [7]. The advantages of railways comparing to other modes are:

- Little emission of CO2: they take about 1,5% of the total emissions form transport in the EU, from 1990 to 2016 they were reduced for 43%;
- Efficient use of land: comparing to roads, tracks use 40 times less land;
- Low energy consumption: it represents 1,8% of transport emissions in the EU and it was reduced for 20% from 1990 to 2016, while transport emission in the same period were increased for 29%;
- In urban areas, it is easier to develop railway stations than airports [9].

Many environmental benefits of railways may be diminished by poor organisation of transport and inefficient management of railway traffic. In this way, the quality of the environment can be deteriorated. The research in the USA (Engl. United States of America – USA), has shown that railway transport is on average for 63% more energy efficient than road transport. This is mostly due to the fact that the greatest part of railway infrastructure has been electrified, which largely contributes to lower emission of dangerous gases [7]. Figure 2, shows a comparison of the emissions of CO2 in grams per passenger km, for different transport modes, where it has been confirmed that railways have several times lower emissions of CO2 comparing to passenger cars and airplanes [10].

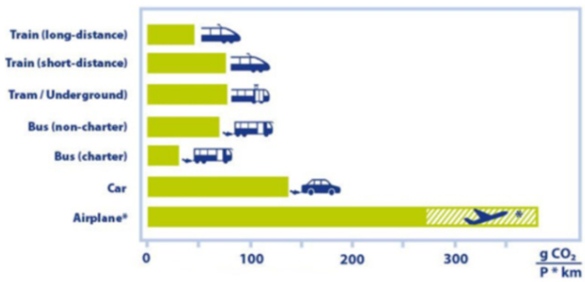

Fig. 2. Comparison of emission of CO2 in grams per passenger km [10]

Noise and vibrations are considered to be the biggest environmental deficiencies of railways. The main sources of noise in railway traffic are the propulsion of vehicle in the area of low speeds, the rolling of wheels on the rail and resistance of the environment, i.e. aerodynamics of vehicles in the area of high speeds. In the area of conventional speeds, the biggest problem is the noise created at the contact between the wheel and rail. This means that in the phase of track operation the level of noise from railway traffic depends primarily on the condition of surfaces at the contact between the wheel and rail, i.e. the causes of noise are roughness of contact surfaces of the wheel and/or rail, irregular geometric shapes of wheels and/or rails in the zone of their contact, then uneven rigidity along the track with discrete rail support, rail assemblies (mechanical with joints, insulated, welded), as well as tracks in curves [8]. Figure 3, presents the creation of noise at the contact between the wheel and rail.

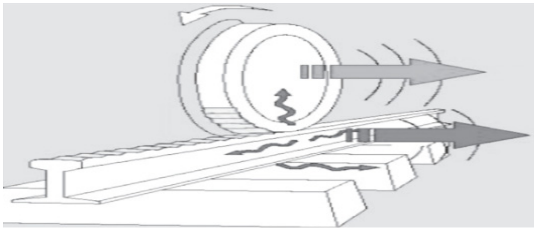

Fig. 3. Principle of generation of noise at the contact of wheel and rail [8]

Control of emission of noise and vibrations from railway traffic, from the aspect of railway infrastructure, is realised in the area of planning, design, construction and maintenance of railway lines [8]. Besides noise and vibrations, a great disadvantage of the railway from the point of view of economic parameters of sustainable development is the small market share, primarily in Europe. In Europe, freight railway transport represents about 16% and passenger transport about 6% out of the total flows of freight and passengers, which is a very small share. In order to increase these percentages, it is necessary to take the measures related to: maintenance and further development of environmentally friendly vehicles and infrastructure, increasing of attractiveness for transport of passengers and goods, reduction of operational costs, efficient use of new technologies through digitalisation, use of new materials, storage of energy etc. and development of the railway sector through education, trainings and improvement of the processes and tools for design, production and work [7].

5. CONCLUSION

Modern urban development imposes the need to introduce better quality, more economic and above all, more environmentally friendly systems for mass public transport of passengers. Given the environmental benefits of railways and cablewayss, especially in terms of pollution of the environment and land occupation, their revitalisationa in urban and suburban transport of big cities represents and imperative of their development. Implementation of new technologies and prescription of standard in the production of means of transport in these modes of transport in terms of tolerable emission of harmful effects ensures a high level of safety, energy savings, lower pollution and harmful effcts on the human environment. In the fight against climate changes, drasctic and rapid reductions of the emission of CO2 are necessary in all sectors, including traffic depending on fossil fuels which is responsible for over 20% of the emissions of CO2 from energy combustion.

In the future, environmental benefits of cableways could make cableway transport competitive with other modes of transport in urban areas. In order to achieve that, cableways should increase their capacity, i.e. they should transport a larger number of passengers per hour. One of the possibilities is to reduce the intervals and distances between the cabins, which can be achieved by additional platforms and thus increase the capacity [6].

Also, railway transport with its environmental advantages over other modes of transport, by taking the measures mentioned in this paper would become more competitive in the market and more represented mode of transport, which would lead to reduction of pollution of the environment.

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ANALYSIS OF THE INTERFACE BETWEEN NATIONAL APPLICABLE GAUGE IN THE BULGARIAN NETWORK AND GAUGE GC, BG AND GA

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Vladimir ZHEKOV[3]

***Abstract** – The report addresses the queries on the conformity assessment of the Construction gauge characteristic of the Commission Regulation (EU) № 1299/2014 from 18 November 2014 regarding the technical specifications for interoperability related to the infrastructure subsystem, which is mandatory for the application in modernization and renewal of railway sections of the main and wide-ranging railway network of the European Union. When determining the conformity, the applicable kinematic ÷ for the upper part are GA, GB and GC, and for the lower part - GI1 and GI2, as defined in standard BDS EN 15273-3. These dimensions are not addressed in the applicable national applicable documents and there are no definitions defined of their application. Documents of the Manager of the Infrastructure of the Bulgarian Railways determine the sections and the applicable dimensions, indicating the nationally applicable construction dimensions - 1-CM2, 1-CM1 and 1-CM and the European dimensions, defined in standard BDS EN 15273-1 ÷ 3. This report examines the interface between the nationally applicable construction gauges 1-CM2, 1-CM1 and 1-CM and the construction gauges defined by the kinematic gauges GA, GB and GC and on the basis of the conclusions made, the possibilities for integration of the gauge rules GA, GB and GC are determined in the national legislation.*

Keywords – railway track, construction gauge, conformity assessment, Regulation № 1299/2014, kinematic gauge

1. INTRODUCTION

The report examines the interface between the nationally applicable construction gauges in the Republic of Bulgaria 1-CM2, 1-CM 1 and 1-CM and the construction gauges GUC-BG, GUB and GUA, determined by kinematic calculations according to the methodology of standard EN 15273-3[1] based on kinematic dimensions GC, GB and GA. The aim of the study is to determine whether compliance with the national gauges can be considered to have achieved compliance with the European dimensions GC, GB and GA. This task is of practical importance in determining the permeability of the routes on the railway network for the main European gauges. The study may also be useful in demonstrating compliance with the requirements of characteristic item 4.2.3.1 "Construction gauge" of Regulation № 1299/2014 [2]. The application of Regulation № 1299/2014 and the technical specifications for interoperability (TSIs) in case of modernization and renewal of railway sections on the main and wide-ranging network of the EU on the territory of the Republic of Bulgaria it is obligatory.

2. PURPOSE OF THE SCIENTIFIC RESEARCH

The Bulgarian regulations for railway define the construction gauges 1-CM 2, 1-CM1 and 1-CM, which to varying degrees provide the provision of rolling stock with static dimensions 03-BM, 02-BM, 1-BM, 0- BM and 1-T, as well as load dimensions "A", "B", "C" 1-BM and 1-T. Most of these dimensions are known as OSGD gauges, and international agreements stipulate their application on the railway corridors of the European space and the OSGD countries. In case of construction gauge 1-CM 2, the passage of static gauge 1-T is provided, which is not widely used in international circulation but defines a significantly expanded profile.

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Today, when most of the main railways are part of the EU's core and wide-ranging network, new projects demonstrate compliance with the kinematic dimensions defined according to the transport code, with GC, GB and GA gauges defined for the country. For existing routes designed and constructed in the past in accordance with national gauges, it is necessary to determine their permeability with respect to gauges GC, GB and GA.

In order to determine the compatibility with the GC kinematic gauge, the NRIC Infrastructure Manager determined the construction gauge GUC-BG. In order to determine the construction gauges based on the kinematic gauges GB and GA, kinematic determinations were performed within the first part of the project "Determination of nationally applicable rules for construction gauges and study of interface with gauges GA, GB and GC" at the University of Architecture, Civil Engineering and Geodesy. Based on the study, the construction gauges of GUB and GUA were determined, which can be used to demonstrate compliance with GB and GA gauges. This study is the second part of the research in the project, aiming to examine the interface between the nationally applicable gauges 1-CM2, 1-CM 1 and 1-CM and the construction gauges GUC-BG, GUB and GUA.

The study aims to determine whether the definition of national gauges can be added to provide some of the gauges GC, GB, GA for which modern European standards determine the need for compliance.

3. RESEARCH METHODOLOGY

In order to achieve the thus defined objectives of the study, the following methodology was chosen:

1. The profiles of gauges 1-CM 2, 1-CM1 and 1-CM are calculated for different horizontal curves from 300 m to 1500 m, with normatively determined cant, according to the methodology determined by Ordinance 58 [3].
2. The calculated profiles are displayed graphically.
3. Graphical comparison of the obtained profiles of 1-CM 2, 1-CM1 and 1-CM with extension in the curves and in straight and construction gauges GUC - BG, GUB and GUA is performed.
4. Analysis of the results and summary.

4. RESEARCH RESULTS

According to the defined methodology, several basic graphical calculations have been made for each of the national gauges.

4.1. Comparison of gauges 1-CM2 with gauges GUC-BG, GUB and GUA

Several gauges have been developed for gauge 1-CM2:

- In straight section;
- At a radius of the curve of 300 m.÷1500 m. with corresponding cant and speed.

The calculations show that the GUB and GUA profiles fit into the gauge profile 1-CM 2 in all cases under consideration.

In all cases under consideration, gauge GUC-BG does not fit in profile 1-CM2.

In the graphical analysis below are shown some of calculations of 1-CM2 gauge with gauge GUC BG/GUB/GUA.

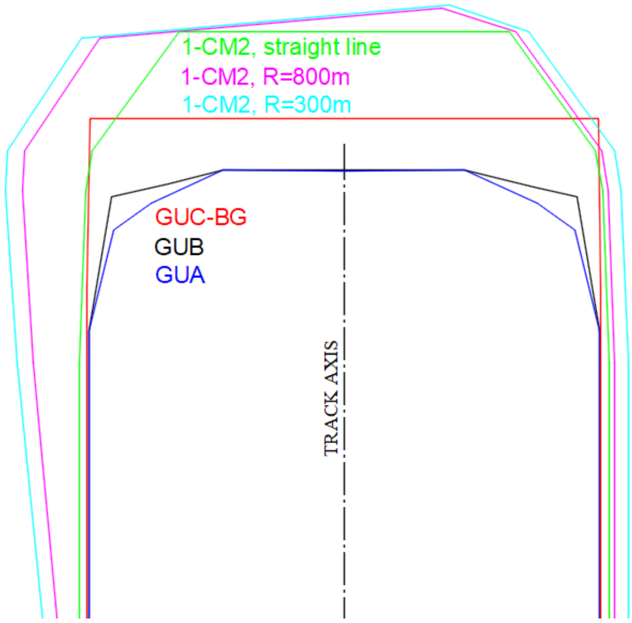

Fig.1. Graphical analysis 1-CM2 – GUC BG/GUB/GUA

4.2. Comparison of gauges 1-CM1 with gauges GUC-BG, GUB and GUA

Identical characteristic profiles have been developed for gauge 1-CM1 as for profile 1-CM2. The calculations show that the GUB and GUA profiles fit into the gauge profile 1-CM 1 in all cases under consideration. Only for profile 1-CM 1 in straight lines a significant approach to the GUB profile is established at a point with coordinates X = 1.76 / Y = 4.31 m in a coordinate system determined by the track axis at the level of the rail head. At this approach point, the GUB profile approaches 5 mm to the 1-CM1 profile in straight lines, but fits completely into it.

In all cases under consideration, gauge GUC-BG does not fit in profile 1-CM1.

In the graphical analysis below are shown some of calculations of 1-CM1 gauge with gauge GUC BG/GUB/GUA.

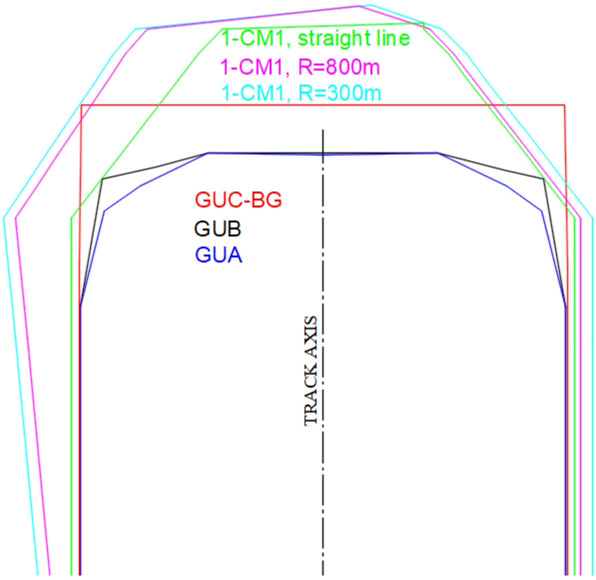

Fig.2. Graphical analysis 1-CM1 – GUC BG/GUB/GUA

4.3. Comparison of 1-CM size with GUC-BG, GUB and -GUA gauges

Identical characteristic profiles have been developed for gauge 1-CM as for profile 1-CM2. The calculations show that the GUA profiles fit into the gauge profile 1-CM in all cases.

In the case of a 1-CM profile, the output of the GUB profile is established in its highest part, but only by 2 mm. Given that the GUB profile has an additional width of 5 cm at the top, it can be tentatively assumed that the profile fits.

In all cases under consideration, the GUC-BG gauge does not fit in the 1-CM profile.

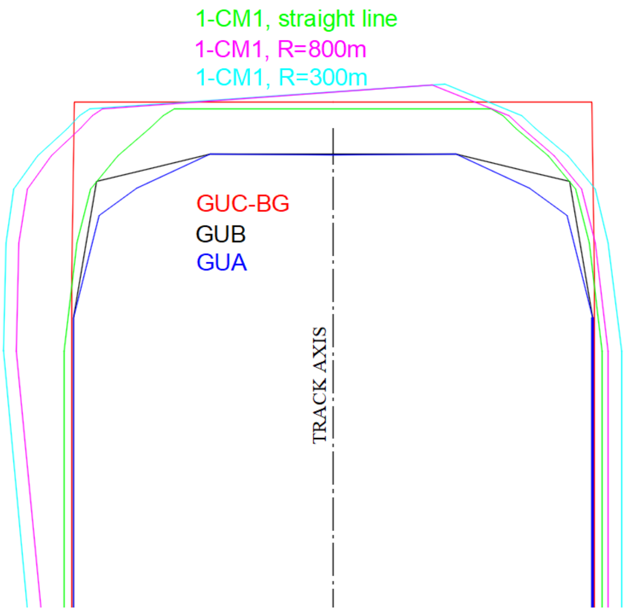

Fig.3. Graphical analysis 1-CM – GUC BG/GUB/GUA

5. CONCLUSION

Several main summaries can be made from the study:

- Rolling stock for gauges GB and GA can move in sections with construction gauge 1-CM 2;
- Rolling stock for gauges GB and GA can move in sections with construction gauge 1-CM 1;
- Rolling stock for GB and GA gauges can move in sections with construction gauge 1-CM.
- In order to ensure the GC gauge, an independent calculations must always be carried out according to the applicable methods, and this can also be done through the GUC-BG gauge. From the above statements, in the presence of existing sections for which only the national gauges are known, a conclusion can be drawn on the basis of what has been shown, and in all cases dimensional studies are required to ensure the GC dimension.

ACKNOWLEDGEMENT

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Vehicle and infrastructure maintenance

ANALYSIS OF THE FAILURES OF BOGIES TYPE T73-AD AND Y32 FROM OF BULGARIAN STATE RAILWAYS

Dobrinka ATMADZHOVA[1]
Vanio RALEV[2]

Abstract *– The paper presents the results of a study on the operational status of a without cradle type of passenger bogies from the Bulgarian State Railways (BDZ) park. The designs of a swininging type passenger bogie in the operation of the Republic of Bulgaria is presented. Referred are most likely common faults of T73-AD and Y32 passenger bogies. Common failures, probable causes probably for the occurrence of failures and ways to minimize them, have been successfully identified using Pareto diagrams. By the finite element method, characteristic zones with probability of failures are determined.*

Keywords – Railway vehicles, passenger cars, bogies, failure.

1. INTRODUCTION

To ensure the design reliability, the appropriately selected materials, the strength stock, the reservation scheme, etc. are of particular importance. The systems ensuring the reliability cover the entire life cycle of the machines, from design and manufacture to operation. Reliability methods are specific to each stage of the life cycle.

2. WITHOUT CRADLE TYPE OF BOGIE FOR PASSENGER CARS - QUALITIES, REQUIREMENTS AND DEVELOPMENT OPPORTUNITIES

In recent decades, the increasing use of without cradle type bogies for passenger cars has been observed as one of the most characteristic trends. The principal feature of this type of bogies is that the necessary elasticity of the connection between the car body and the bogies in the horizontal-transverse direction is not provided on the basis of the properties of the physical pendulum by the so-called swing device, and without such a device based on the elastic deformations of the spring elements in the horizontal-transverse direction under the action of the respective forces [1]. Without cradle type of bogies offers special conveniences with the most widespread spring elements in the secondary spring suspension - the cylindrical coil springs. The cradleless principle has also been successfully applied to pneumatic springs, which are becoming more and more widespread.

3. BOGIE CONSTRUCTIONS WITHOUT CRADLE IN OPERATION OF THE REPUBLIC OF BULGARIA

3.1. T73-AD bogie

The bogie T73-AD (Fig. 1) is the construction of Bulgarian bogies for passenger cars B-84 type "Seagull".

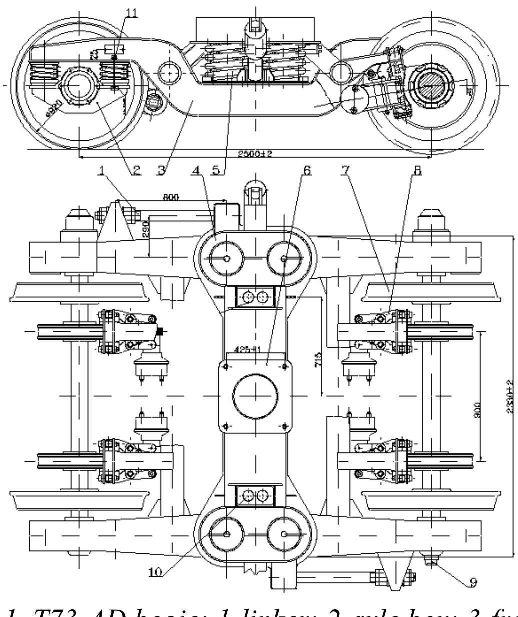

Fig.1. T73-AD bogie: 1-linker; 2-axle box; 3-frame; 4- bolster; 5-secondary spring suspension; 6-center pivot; 7-wheelset; 8-brake system; 9- system against dragging; 10- side bearer; 11-grounding.

The bogie is a without cradle type [2] and is equipped with a disc brake. Its construction allows the

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installation of a magnetic rail brake, as well as an automatic regulator of the braking force, depending on the load of the car. The base of the bogie is 2.5 m, design speed 160 km/h.

The wheelsets have wheels, monoblock type with a diameter in the rolling circle of 920 mm and are for axle load not exceeding 16.5 t/axle. Between the wheels of individual hubs are pressed two brake discs having internal ribbing to remove heat from the brake. The bearing of the axle in the socket has two single-row cylindrical roller bearings with standard dimensions ϕ120x240x80.

The frame is an "H" - shaped (i.e. open type) welding structure consisting of two longitudinal side beams (sides) with a box-shaped cross section, connected by two transverse steel pipes. The shape of the longitudinal side beams is specific for the common in other European countries swing less bogie constructions - type "swan neck" or "Seagull".

The spring suspension of the bogie is two-stage made entirely of springs. The static sag of the spring suspension is significantly larger than the other bogies considered; at maximum payload (12 t per wagon), it is 320 mm, of which almost 80% falls on the secondary spring suspension. The primary spring suspension for each axle box is made of two sets of double-row coil springs lying on vibration-insulating rubber rings attached to the "wings" of the axle box body.

The axles are guided by spindles, and between the spindle and the taller there is a radial clearance of 7 mm, providing self-steering of the wheels (radial location in a curved section of the road). It is possible to install a odometer on one of the bogie axles.

The secondary spring suspension consists of four elastic sets of concentrically arranged coil springs with a rubber sleeve in them. The rubber bushing provides a bilinear characteristic of the secondary spring suspension, being switched on when the bogie load exceeds the normal one (when the car is overcrowded). In this way, the wagon is protected against loss of lateral stability under heavy overloads and does not violate the condition of not exceeding the maximum permissible difference of 80 mm between the height of the buffers in the loaded and empty state. The transverse elastic mobility (elastic connection) between the wagon car body, respectively the over sprung beam of the bogie and its frame is realized by the transverse horizontal elasticity of the central springs (swing less device of the secondary spring suspension). On top of each elastic set of the secondary spring suspension, between it and the over sprung beam there is a taller and a rubber disk; moreover, the diameter of the rubber disc is much smaller than the diameter of the outer spring, in order to increase the hinge effect of the rubber disc supports and hence to reduce the horizontal stiffness of the springs of the secondary spring suspension. When the horizontal deformation of the set or the transverse displacement of the spring beam exceeds 20 mm, the elastic deflector is deformed, which has a strong progressive characteristic.

3.2. Bogie Y32

The Y32 type bogie (Fig. 2) [3] was designed for SNCF's Corail wagons by De Dietrich. The company De Dietrich (now Alstom) has produced more than 6,000 bogies used in France, Belgium, the Netherlands, Portugal, Romania, Turkey, Morocco and since April 2013 Bulgaria (30 sleeping cars type WLABmz).

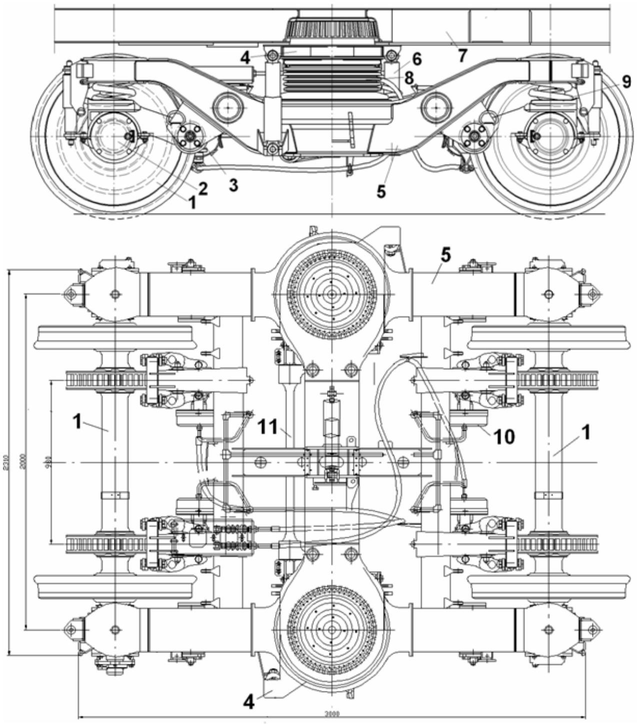

Fig.2. Y32 type bogie on WLABmz sleeping cars 1- wheel; 2- axle box; 3 - connection "axle box-frame"; 4 -bolster; 5 - frame; 6 - damping system; 7 - car frame; 8 - secondary spring suspension; 9 - primary spring suspension; 10 - braking system; 11 – traction.

Wheelbase - 2560 mm; Distance between pages - 2000 mm; Wheel diameter - 920 mm; Bogie tare - 6000 kg; Maximum design speed - 160 km/h.

The primary and the secondary spring suspensions have a two-row cylindrical coil spring.

The frame of the bogie type Y32 consists of two longitudinal side beams, two steel pipes and a middle part with a box-shaped section.

The overrun beam of the bogie type Y32 consists of an upper leaf, a lower leaf, a middle part and two conical upper supports of the springs from the secondary spring suspension and two brackets.

4. ANALYSIS OF INDIVIDUAL ELEMENTS AND ASSEMBLIES FROM PASSENGER CARRIERS BOGIES

Here will be considered only those of the elements and units of the bogie, which require increased attention due to coincidence of circumstances related not only to operational factors, but also to those of organizational and administrative nature:

A) In the first place - are the object of sharpened attention - the joints between the sides and transverse beams (pipes). These are the corners that represent welds. In the prescriptions of the institute (NITIZHT) the requirement for obligatory defectoscopy of the welds in this knot is set.

B) Secondly, the consoles (ears) through which the longitudinal lenkers are connected to the bolster and the sides of the bogie frame, in and around the places of their connection, are the object of sharpened attention. To reduce the high stresses resulting from different train conditions for the T73-AD bogie, it is recommended to increase the radius of curvature at the base of the brackets and improve the quality of the welds connecting the latter to the spring beam or the page and recommendations. of the linker rubber "hinges".

C) Thirdly, cracks can be expected under certain conditions in the lower sheet of the spring beam around the places near the edges of the brackets, perceiving the transverse forces as reactions of the rubber pads. In these places, cracks occur in bench fatigue tests at 6 million cycles and recommendations for rib welding are given.

4.1. Operational observations of passenger bogie type T73-AD

For the period from 01.01.2017 to 31.12.2018 in the repair shop of the depot "Nadezhda" arrived wagons B'84 with bogies T73 AD and the percentages of failures which are shown by Pareto-diagram (Fig. 3).

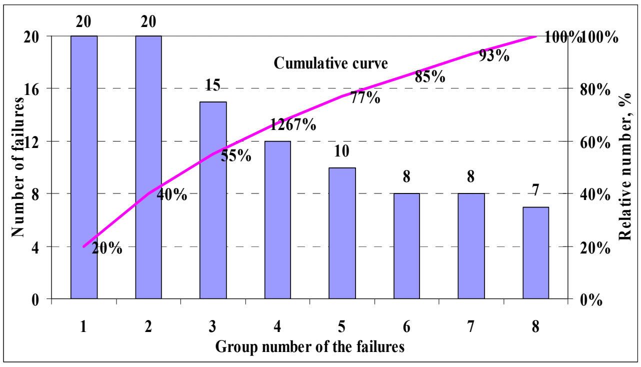

Fig.3. Failures to elements of bogie T73-AD. 1- frame; 2- bolster; 3- brake system; 4- wheel axles; 5- side bearer; 6- dampers; 7- spring suspension; 8- centre pivot

4.2. Operational observations of passenger bogie type Y32

For the period from 01.01.2018 to 31.12.2019 in the repair shop of the depot "Nadezhda" have arrived sleeping cars type WLABmz, whose bogies type Y32 needed repair or repair of failures, the percentages of failures of which are shown by a Pareto diagram (Fig.4).

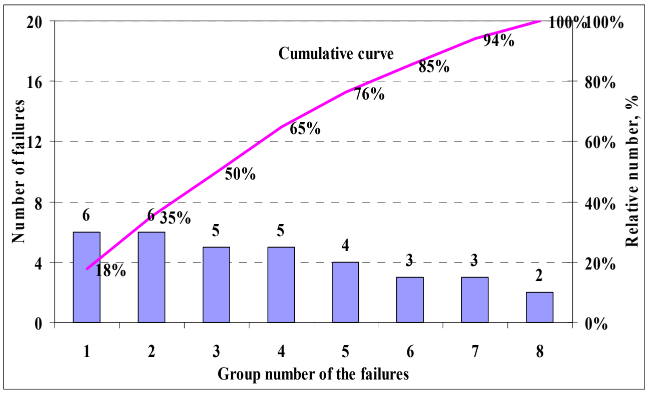

Fig.4. Failures to Y32 bogie elements. 1- frame; 2- overhead spring beam; 3- brake system; 4- wheel axles; 5- connection "axle box-frame"; 6- dampers; 7- traction; 8- spring suspension

5. ZONES WITH PROBABILITY FOR FAILURE

5.1. Stress condition of frame and bolster for bogie type T73-AD

In fig. 5 shows the stress state of the bogie frame, the maximum value being 80.46 MPa obtained in the axle box support. In fig. 6 shows the stress state of the bogie oversprung beam, the maximum value being 359.8 MPa obtained in the vertical support of the left slider. The obtained stresses and strains are within the permissible limits, but under cyclic loading cracks can occur due to fatigue of the material.

5.2. Stressed condition of frame and spring beam for bogie type Y32

In fig. 7 shows the stress state of the bogie frame, the maximum value being 80,654 MPa obtained in the central and axle supports. In fig. 8 shows the stress state of the bogie oversprung beam, the maximum value being 225.5 MPa obtained in the connection of the middle part of the spring support from the secondary spring suspension and the connection with the brackets. In conclusion of the present studies, the recommendation for monitoring the operational condition of:

- the frames of the two bogies in the area of the spinton connection, the middle conical part and the "page-cross links" connection;
- a spring beam from the two bogies in the area of slides, the spring supports of the secondary spring suspension and the connection of the beam with brackets

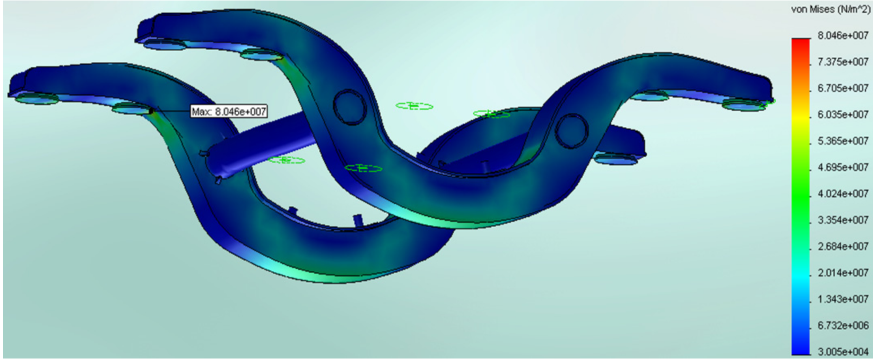

Fig. 5. Stress state of the frame on bogie T73-AD

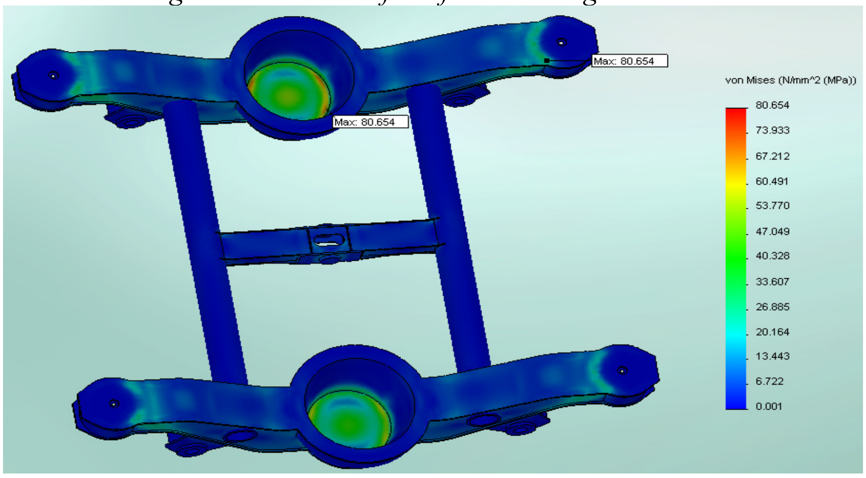

Fig. 7. Stress state of the frame on the Y32 bogie

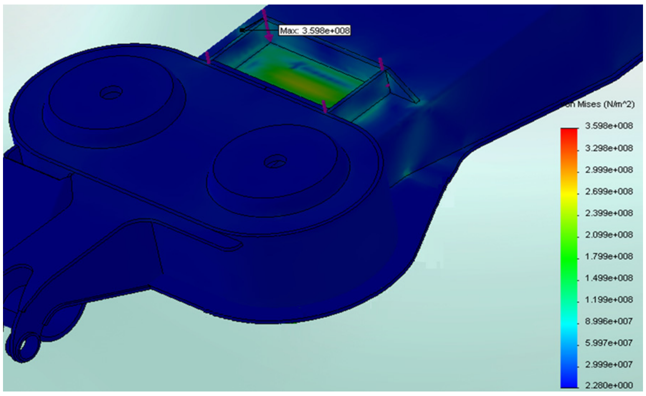

Fig. 6. Tension condition of the bolster of the bogie T73-AD

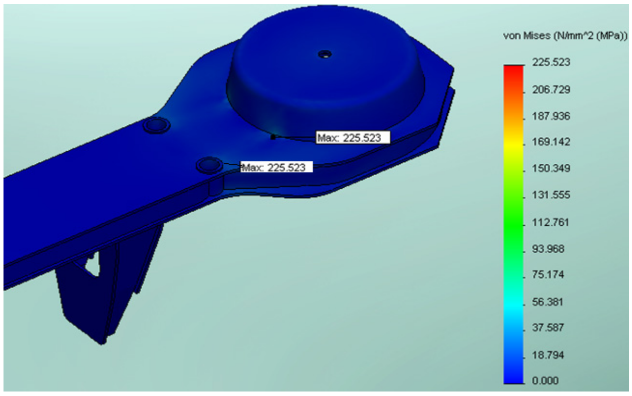

Fig. 8. Stress condition of spring beam of the bogie Y32

6. CONCLUSION

The publication presents the constructions of passenger bogies without swininging in the operation of the Republic of Bulgaria - the passenger bogies type T73-AD and Y32. The most common faults of the passenger bogies of the swininging type are indicated. Pareto diagrams show failures of the specified bogie structures from their operational monitoring. By the finite element method, characteristic zones with probability of failures are determined.

As a result of the research in design, production and repair the object of sharp attention should be:

➢ the places of connection between the sides and the cross beams (pipes). From the frame;

➢ spindle connection area, middle and axle support part of a page of the frame;

➢ the brackets for connection of the longitudinal linkers with the spring beam and the sides of the bogie frame;

➢ the upper and lower leaf of the oversprung beam in the area of the sliders and around the places near the edges of the brackets.

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XIX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS RAILCON '20

MODELLING AND NON-DESTRUCTIVE TESTING OF HEAD CHECK DAMAGE OF RAILWAYS

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Reka ERDEI[2]

Abstract – *Defects of rails might be formed during production and operation. During production rails have to be appropriate to strict standards, and various material testing have to be performed in order to minimize chance of defects in rails. On the other hand, load of rails significantly increased in the last years, as railway traffic, speed of trains and axle load increased. Effect of this growth in load of rails leads to raise the chance of forming and spreading defects during operation. In case of rails with high railway traffic, small, parallel cracks might appear on the running interface, and these small cracks are able to spread because of cyclic loading. This damage is called "rolling contact fatigue, RCF" or "head check" damage, what might cause complete break of rail. Detecting in early stage of head check damage is very important, but serious challenge for material testing experts. Non-destructive material testing and modelling were performed and results of modelling and testing were compared in order to determine optimal testing parameters for detecting damage of rails in early stage.*

Keywords – Head check damage, maintenance, early stage, modelling, non-destructive testing.

1. INTRODUCTION

Rail transport is a significant proportion of transport, and ensuring safety is very important. Trains and rails have to be appropriate to strict standards, and non-destructive testing and maintenance plays an important role in safe operation. In the last decades, railway traffic, speed of trains, axle load of trains, and load of rails are significantly increased. Cycle load of rails cause small, parallel cracks on the running surface, what is called "head check" or "rolling contact fatigue, RCF" damage. Head check damage of rails might cause complete break of rails, and endanger rail transport, so detecting of head check damage of rails is important task in order to avoid accidents. Non-destructive test methods (penetration test, magnetic particle test, eddy current test and phased array ultrasonic technique with modelling) were performed on head check damaged rail samples, in order to determine, which non-destructive testing method is applicable to detect head check damage in early stage. After non-destructive tests, rail samples were cut, and embedded into resin, then microscopic measurement and hardness test were performed on rail samples, in order to validate results of performed non-destructive tests.

2. FORMING AND GROWING PROCESS OF HEAD CHECK DAMAGE

Head check damage of rails is caused by axle load of trains, and location of forming of small, paralell hairline cracks is the running surface of rails. These small hairline cracks are able to spread because of cycle load. In the early stage, spread of cracks is slow and angle of cracks are 20-35° with the running surface of rails. In the early stage, head check damage is not endangering safety of rail transport, but difficult to detect the damage with non-destructive testing methods.

After slow spreading stage of cracks, cracks might be branching and crack-growing direction is changing. Cracks in this stage are spreading towards the core of rails. Growing speed of cracks is increasing significantly, and might cause breakaway of portions and/or complete brake of rails [1]. Forming and growing process of head check damage can be seen in Fig. 1.

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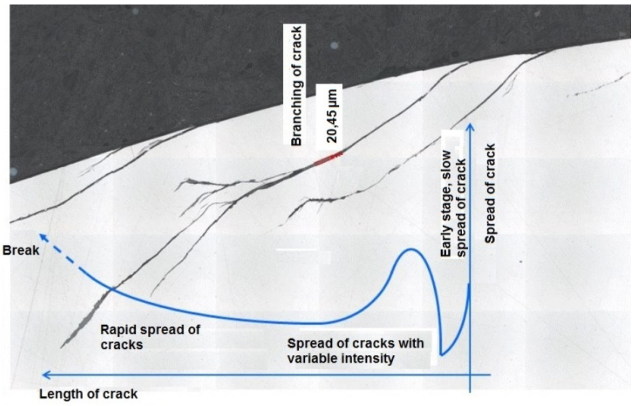

Fig. 1. Forming and growing process of head check damage [2]

3. RESULTS OF MODELLING AND NON-DESTRUCTIVE TESTS OF SAMPLES

3.1. Penetration and magnetic particle test

Aim of penetration and magnetic particle tests were to determine, is head check damage detectable by these methods in early stage. Result of penetration test can be seen in Fig. 2., and result of magnetic particle test can be seen in Fig. 3.

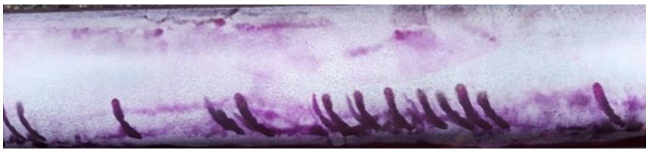

Fig. 2. Result of penetration test

Fig. 3. Result of magnetic particle test

Based on results of penetration and magnetic particle tests, these methods are applicable to detect head check damage in early stage. On the other hand, these non-destructive testing methods are not applicable to perform economically in case of long rails. Furthermore, depth of cracks can not be determined based on results of penetration and magnetic particle tests.

3.2. Eddy current test

Eddy current test was also performed in order to detect and sizing head check cracks of rail samples. Main test parameters of performed eddy current test can be seen in Tab. 1.

Tab. 1. Main parameters of eddy current test

Eddy current test equipment	**Olympus Nortec 600**
Test probe	Olympus PL/500kHz-2MHz/Du
Test frequency	500 kHz
Horizontal gain	65,0 dB
Vertical gain	65,0 dB

Calibration of eddy current test equipment was performed by steel reference specimen with 0,2; 0,5 and 1 mm depth notches. Eddy current indication of reference specimen can be seen in Fig. 4. and eddy current indication of rail sample can be seen in Fig. 5.

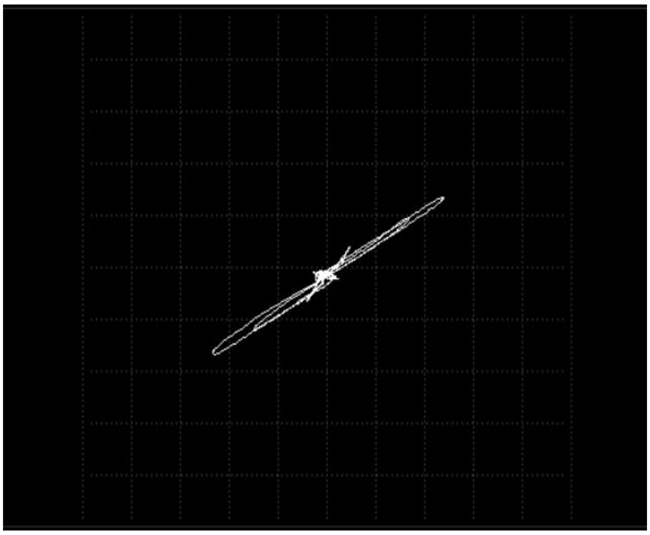

Fig. 4. Eddy current indication of 0,2; 0,5 and 1 mm depth notches

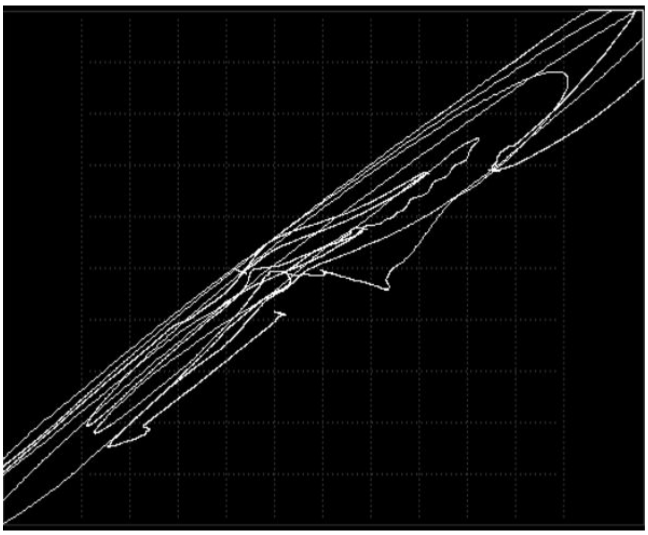

Fig. 5. Eddy current indication of rail sample

Based on result of eddy current test, head check cracks can be detected by eddy current test method. In case of tested rail sample, depths of cracks are significantly greater than 1 mm, measured depths of cracks were 3-4 mm. Defects, caused by head check damage can be detected in early stage, eddy current tests can be performed economically in case of long rails, and depth of cracks can sized, but test parameters should be optimized before test.

3.3. Modelling and phased array ultrasonic testing

In order to determine optimal testing parameters of phased array ultrasonic testing, computer modelling was performed. Modelling was carried out by CIVA 2020 program, assuming a crack with 20 mm length and 3 mm depth, starting from the running surface. Result of CIVA 2020 modelling can be seen in Fig. 6.

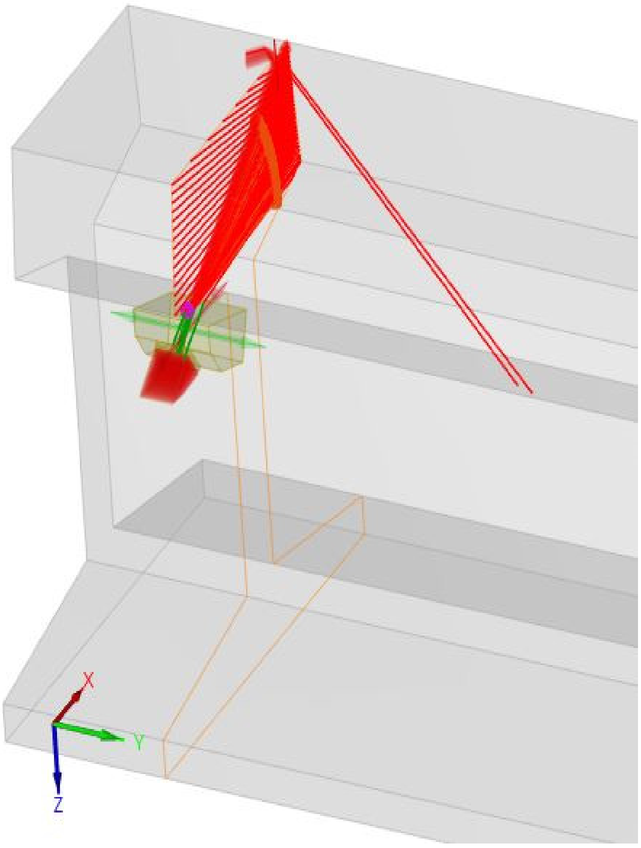

Fig. 6. Result of CIVA 2020 modelling

Based on result of computer modelling, small portion of sound beam reflects back to the phased array ultrasonic probe, high gain needs to be chosen. High gain cause higher noise level, material testing experts needs to take into account this effect.

Based on result of modelling, chosen main parameters of phased array ultrasonic test can be seen in Tab. 2.

Tab. 2. Main parameters of phased array ultrasonic test

Ultrasonic test equipment	**Olympus OmniScan MX2**
Test probe	Olympus 5L16
Wedge	Olympus SA10-N55S IHC
Angle	40°-65°
TCG	Ø=3mm side drilled holes, 27; 39; 51 and 63 mm depth
TCG Gain	21 dB
Coupling	Sonotech Soundsafe NSN 6850-01-157-4338

Result of phased array ultrasonic test can be seen in Fig. 7.

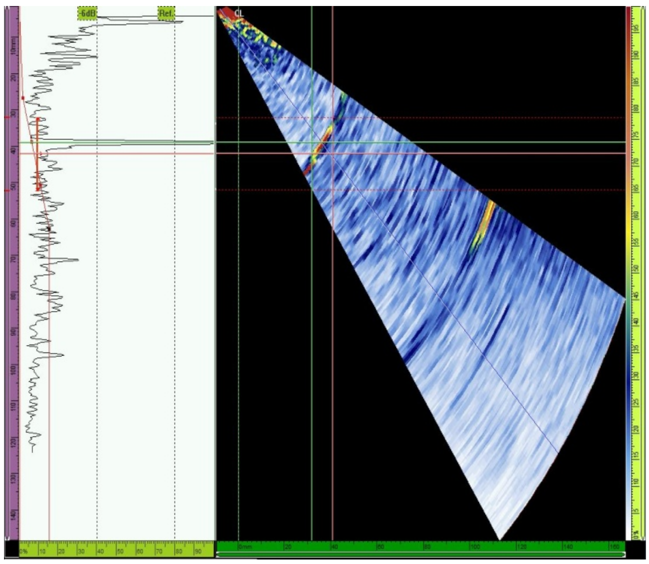

Fig. 7. Result of phased array ultrasonic test

Based on result of phased array ultrasonic test, defects caused by head check damage, can be detected in early stage. Depth of cracks of tested samples in some cases were over 3 mm. In case of long rails, phased array ultrasonic tests can be performed economically, and depth of cracks can be sized, but test parameters should be optimized before test, and continuously coupling is needed during the test.

4. MICROSCOPIC AND HARDNESS TESTS

After carried out and evaluated non-destructive tests, tested samples were cut and embedded into resin, in order to validate results of non-destructive tests.

4.1. Microscopic measurements

Microscopic image of head check crack of tested rail sample and grain structure can be seen in Fig. 8.

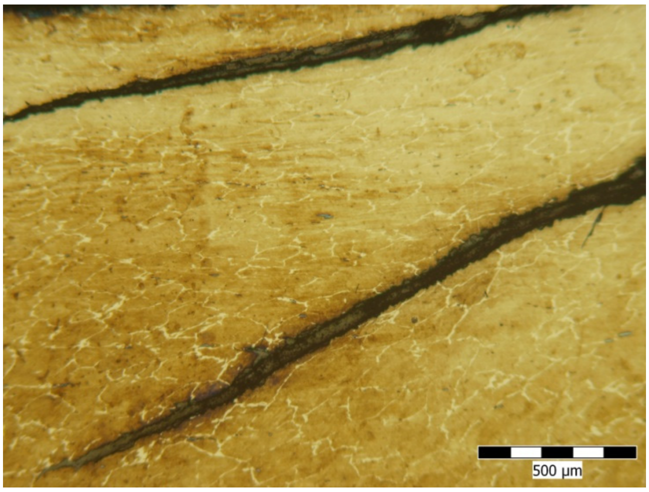

Fig. 8. Microscopic image of tested sample, mag. 50X

Based on microscopic test, spread of cracks of tested samples are transcrystalline. Results of microscopic measurements of size of cracks can be seen in Tab. 3.

Tab. 3. Results of microscopic measurements

ID	Depth (mm)	Length (mm)
Sample 1; crack 1	3,5	9,5
Sample 1; crack 2	2,0	5,8
Sample 1; crack 3	2,7	7,4
Sample 1; crack 4	2,4	6,4
Sample 2; crack 1	3,9	11,9
Sample 2; crack 2	2,2	7,5
Sample 2; crack 3	2,3	7,9
Sample 2; crack 4	0,8	4,6
Sample 2; crack 5	3,2	11,3
Sample 2; crack 6	3,9	11,5
Sample 3; crack 1	4,1	9,7
Sample 3; crack 2	1,7	3,9
Sample 3; crack 3	3,4	6,8
Sample 3; crack 4	3,6	6,7
Sample 3; crack 5	3,9	10,9

According to results of microscopic measurements, depth of cracks were in some cases over 3 mm, along with results of eddy current and phased array ultrasonic tests.

4.2. Hardness test

After microscopic measurements, HV5 hardness tests were performed. Three series of hardness tests were carried out, measured hardness of samples, depending on distance from running surface can be seen in Fig. 9.

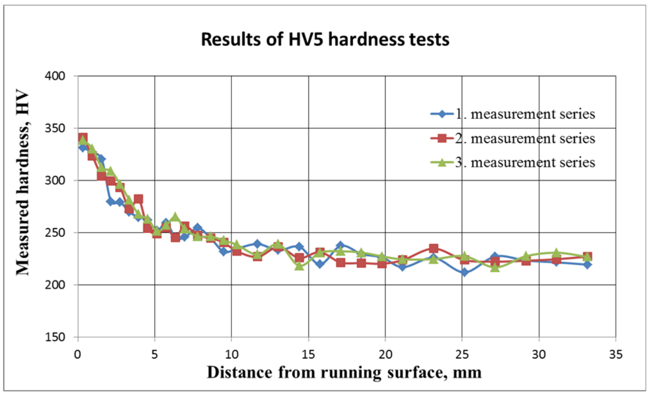

Fig. 9. Results of HV5 tests

Based on results of hardness tests, tested rail samples significantly hardened near the running surface, this hardening is caused by load of trains.

5. CONCLUSION

Head check damage might cause complete break of rails. Detecting and sizing head check cracks in early stage by non-destructive testing methods is very important in order to avoid accidents, but difficult task for material testing experts.

Cracks can be detected in early stage by penetration and magnetic particle tests, but can not be sized, and these tests can not be performed economically.

In case of eddy current and phased array ultrasonic tests, detecting and sizing head check cracks is available. Results of these tests showed great correlation with each other and microscopic measurements, but determine optimal test parameters before tests is very important.

ACKNOWLEDGEMENT

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XIX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS RAILCON '20

DEVELOPING ADVANCED SUBSYSTEM FOR SECURING STEEL COIL CARGO ON SHIMMNS WAGON CRADLES

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Milan BOJOVIĆ[2]
Marko TOPALOVIĆ[3]
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Abstract *– In this paper design improvement on assembly used for securing steel coils on Shimmns wagon is presented. The main disadvantage of current solution is that it is very slow for securing coils with smaller width, since safety mechanism is positioned manually for each coil. We needed to solve this issue without compromising function and reliability of the current locking mechanism. In the current design spindle rotation causes coupled movements of securing arms which constrain lateral movement of coils by applying significant force, but if the coil is not adequately centered, the arms on one side will not come in the contact with the coil, as arms on both sides are coupled on the same spindle and are moving symmetrically. The Finite Element Method is used to analyze the new solution and verify that it meets all the safety requirements prescribed in the standards. The improvement of existing solution is done with the half-nut mechanism which enables arbitrary, decoupled initial positioning of arms and clamping with threaded spindle when the arms are brought in contact with the coil. The new solution is implemented, and has proven to be practical and reliable in the exploitation.*

Keywords – Shimmns wagon, Steel coils, Securing mechanism, FEM analysis

1. INTRODUCTION

The Shimmns freight wagons are used for transportation of steel coils which can vary in diameter, width and weight. These coils are placed into five cradles, and each coil is fixed using four securing arm subsystems. Proper positioning and secure fastening of these coils are essential for safety during the exploitation. During their lifetime, Shimmns wagons are subjected to different forces and strains, and must be able to withstand a wide range of load cases defined in the standards. Particular standards used are TSI [1] and BS EN 12663-2 [2]. Currently, each coil is secured manually, which is a slow process performed on many wagons, so the efficiency of this securing subsystem needed to be increased.

3D CAD model of the securing mechanism is created using provided technical documentation, and the numerical analysis of the worst case scenario, according to standards [1] and [2] was performed using the Finite Element Method (FEM) [3]. FEMAP software [4] is used as pre and post-processor for the FEM mesh generation and display of the results. FEM analysis was performed using NX Nastran solver, which is built in FEMAP. The results show that the maximum calculated stress is below permissible stress, and based on these conclusions, modifications to existing wagons were performed. The upgraded wagons perform well in the exploitation, and the new securing mechanism behaves like predicted.

In the next section, we will describe the loading of analyzed Shimmns wagon, and show the required service (fatigue) load case that wagon securing arms need to withstand. After that, we will describe in detail FEM model of this assembly, and will present analysis results. Based on these results, we will draw a conclusion that the proposed new design is safe for the exploitation, which is proven on the real wagons.

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2. THE SHIMMNS WAGON LOADING

A technical description of four-axle bogie wagon type Shimmns is given in [5]. The wagon is designed for transportation of sheets coils that are loaded in the horizontal position onto five cradles. The maximum total weight of all steel coils combined is 68 tons. This weight can be achieved using different combinations of coil width and diameter, but for the purpose of analysis of the assembly for coil securing, we must consider the worst case scenario [6], which is shown on Fig. 1.

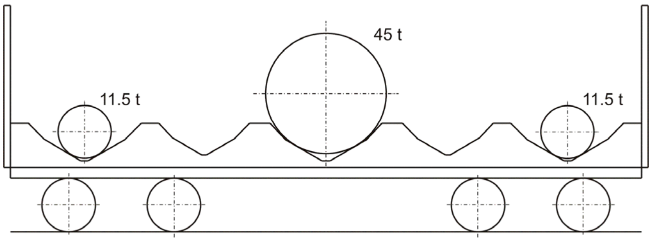

Fig.1. Big coil in the middle, smaller on front and back cradle

In this load case, a coil weighing 45 tons, which is the maximum coil weight, is placed in the middle crate, so redesigned securing mechanism must hold this big coil firmly secured to the wagon structure. Service (fatigue) loads of securing pin assembly in lateral direction are specified by TSI [1] and BS EN 12663-2:2010 [2], Clause 5.2.5.1, Tab. 13. Loading scheme of securing pin assembly is shown in Fig. 2.

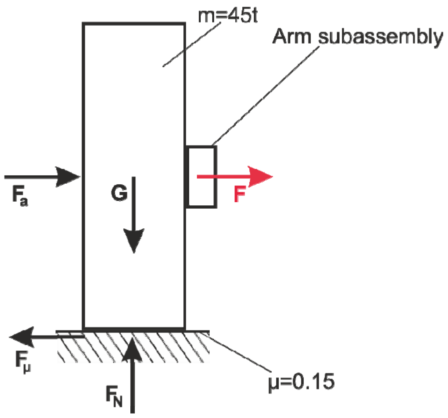

Fig.2. Scheme of model loading

According to loads shown in the previous figure and friction coefficient (steel-steel, lubricated and greasy) according to [7], forces acting on the coil are given in the next table.

Tab. 1. Forces acting on the largest coil (45 t)

G=mg=450 kN	F_a=0.2 m g=90 kN
F_N=G=450 kN	F_μ=μ F_N=67.5 kN
F=F_a- F_μ=22.5 kN	F_1=F_2=F/2=11.25 kN

Force in the lateral direction is divided in two equal parts F_1 and F_2 acting on two arm mechanisms.

3. FEM MODEL OF SECURING ARM SUBSYSTEM

The securing arm mechanism of the Shimmns wagon is shown in Fig. 3.

Fig.3. Securing arm on Shimmns wagon

This assembly is modeled in 3D and analyzed using FEM [4], in order to test the proposed modifications. The new design enables fast decoupled movement of securing arms, and when the arms are in contact with the coil, the mechanism can be used to lock the half-nut with the housing firmly gripping the spindle. Now operators can manually rotate the spindle to tighten the clamp of securing arms on the coils. The FEM model of the whole securing arm assembly is shown in Fig. 4. viewed from the upside down for the best details.

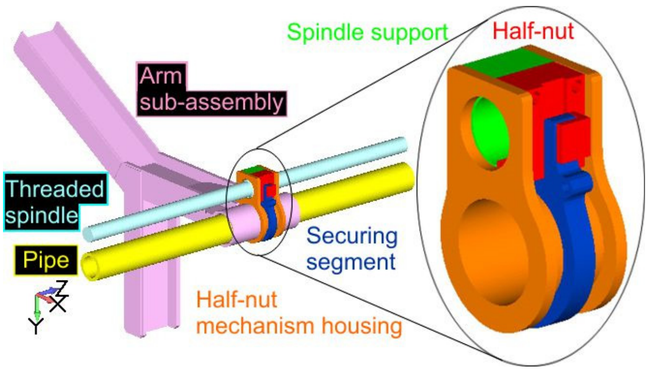

Fig.4. Securing arm assembly

The assembly consists of arm subassembly, pipe, threaded spindle, securing segment, half-nut housing and half-nut, which are shown in Fig. 4.

The arm subassembly, pipe, securing pin and segment, as well as half-nut mechanism housing, are all made of steel S355J2+N (same as the most of the Shimmns wagon). Threaded spindle is made of steel C45E. The Half-nut is made of steel 42CrMo4. The physical properties of steel are given in Tab. 2.

Tab. 2. Physical properties of steel

E [N/mm²]	ρ [kg/mm³]	ν
$2.10\cdot10^5$	$7.85\cdot10^{-6}$	0.3

The values in Tab. 2. are the same for all 3 steels, however, their mechanical properties are significantly different, which can be seen in Tab. 3.

Tab. 3. Mechanical properties of used materials

Nominal thickness, or diameter t [mm], d [mm]	Minimum yield strength, R_{eH} [MPa]	Tensile ultimate strength, R_m [MPa]
S355J2+N		
t≤16	355	470-630
C45E (+QT)		
t≤8, d≤16	490	700-850
42CrMo4 (+QT)		
t≤8, d≤16	900	1100-1300

According to the construction type, 3D elements (tetrahedral elements with midside nodes and linear hexahedral) were used for creating the FEM mesh, Fig. 5. to Fig. 9. The assembly is modelled in details with 397374 nodes and 286981 elements in total. Tab. 4. shows number of nodes and elements per part.

Tab. 4. Number of elements and nodes foe each part

Subassembly name	**Number of elements**	**Number of nodes**
Arm subassembly	99492	139992
Pipe	22080	33264
Segment	4898	6801
Threaded spindle	103765	135067
Half-nut housing	30520	38611
Half-nut	26221	42635

Designing the new securing mechanism required special attention to be paid to contacts. The contact between arm sub-assembly and pipe occurs in two places (highlighted blue), Fig. 5.

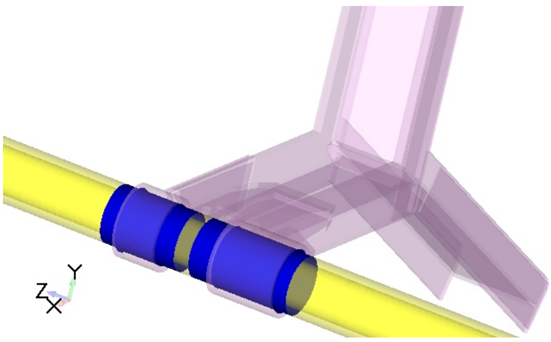

Fig.5. Pipe-arm sub-assembly contact

Since these are just two parts, we could define just one contact pair, however the contact surface would be much greater and calculation time slower, so we defined two contact pairs for pipe arm sub-assembly contact. The entire FEM model contains 25 contact pairs, which is the result of our attention to detailed modelling, focused on both the accuracy, and the analysis time. Fig. 6. shows one of the most crucial contact pairs between threaded spindle, and half-nut.

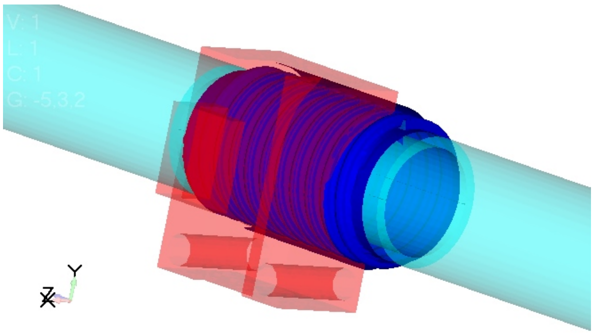

Fig.6. Contact between spindle and half-nut

Two contacts between the half-nut and the spindle support are shown in Fig. 7.

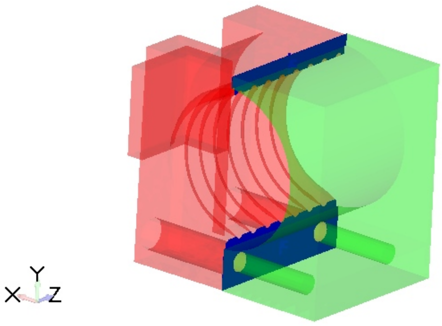

Fig.7. Half-nut spindle support contact

4. FEM ANALYSIS RESULTS

Within the calculation there is a system of two million and four hundred thousand equations being solved. Results show that for every part calculated stress is under permissible stress give in Tab. 3.

For arm subassembly maximum Von Mises stress of 292.9 MPa is shown in Fig. 8.

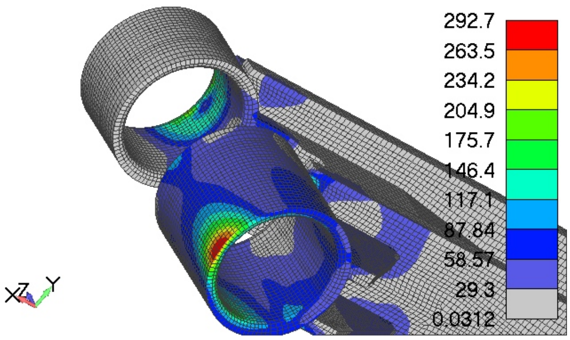

Fig.8. Significant loading zone of arm sub-assembly

Fig. 9. shows Von Mises stress for half-nut housing.

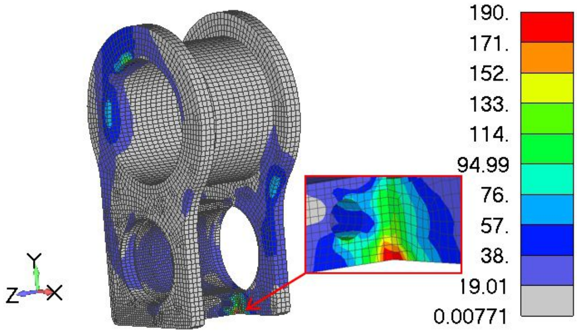

Fig.9. Von Mises stress field – half-nut housing

In case of spindle, the maximum Von Mises stress is 328.1 MPa as seen in Fig. 10., which justifies the usage of stronger, more expensive material C45E.

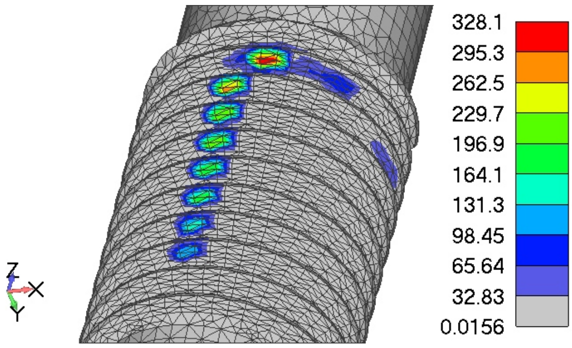

Fig.10. Von Mises stress field – spindle

The most loaded part is the half-nut, which is made of 42CrMo4 so it can withstand maximum calculated stress, shown in Fig. 11.

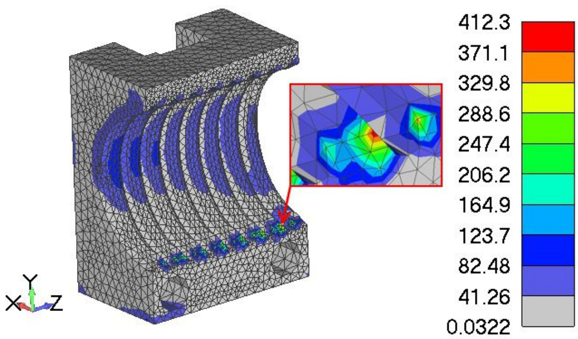

Fig.11. Maximum Von Mises stress half-nut

Half-nut mechanism displacement in the x direction is shown in Fig. 12.

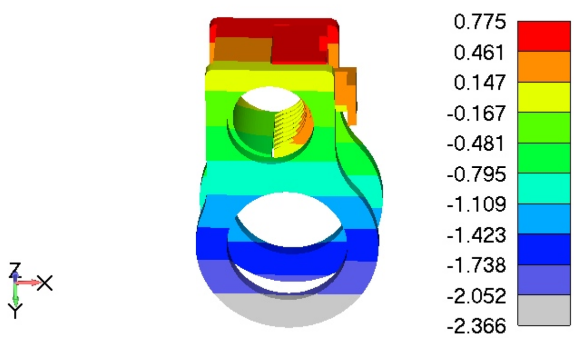

Fig.12. Half-nut mechanism displacement

Fig. 13. shows in more detail the transversal displacement between the half-nut and the spindle support. This displacement is small enough not to cause the mechanism malfunction or failure.

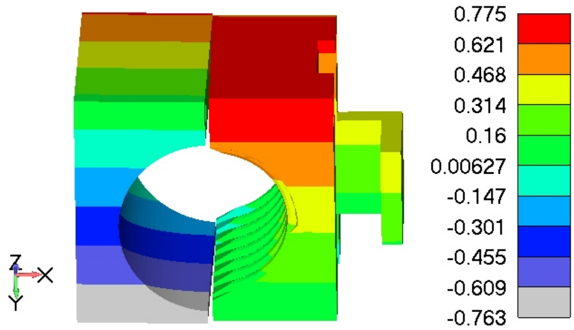

Fig.13. Half-nut and support x displacement

5. CONCLUSION

Based on the results of the FEM analysis described in the previous section, the securing mechanism for Shimmns wagon needed to be made out of 3 different steels in order to withstand service (fatigue) load defined in [1] and [2]. Calculated displacements do not affect functionality of analyzed mechanism.

This solution is already implemented on existing wagons in service, thus improving their functionality and ergonomic quality.

ACKNOWLEDGEMENT

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XIX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
RAILCON '20

RELIABILITY AND SAFETY OF AXLE-WHEEL ASSEMBLY

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Tihomir LATINOVIĆ[3]

Abstract – *The reliability of the axle wheel assembly is very important for the safety from railway accidents that can cause human losses, high material costs and environmental impact. The reliability value should be near one, however its value never reaches its maximum. Many parameters affect its size and are related to the formation of the assembly and its monitoring during operation. Therefore, it is necessary to anticipate and implement sensors that indicate in a timely manner the identification of parameters that affect the decline in reliability and the possibility of assembly failure. The UIC regulations for this assembly have approximate values, and every participant in the creation of this assembly and its operational monitoring remains a technological secret of the participants. In the formation of the assembly, the parameters are: the size of the overlap, the quality of the machinig surfaces, the direction of the unevenness, the geometric accuracy of the shape and position, the lubricant and its parameters, and the application technology. During use: number of variable loads, monitoring the influence of the possibility of temperature rise in the zone and around the assembly zone, the influence of microcracks, etc.*

Keywords – wagon axle, reliability, safety, axle assembly

1. INTRODUCTION

The reliability of elements and assemblies in construction and devices is very important for the safety of their use. In railway vehicles, reliability is very important because the consequences of accidents cause high material costs and often inevitably loss of human lives and severe injuries. Vital assemblies on railway vehicles are: brake devices, axle assemblies, traction-buffer devices, bogie, etc. This paper deals with axle assemblies.

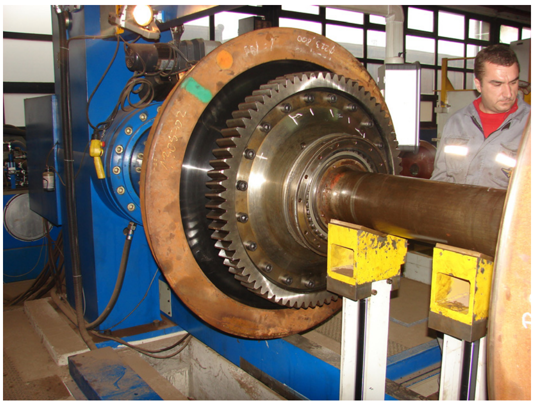

Fig. 1. Axle assemblies of traction vehicles

There are differences between axle assemblies for traction vehicles [1], Figure 1, and for towed vehicles [2], Figure 2, in terms of their load and the complexity of the stress state that occurs in operation. Axle assemblies (axle + shaft) for traction vehicles have significant torsional stresses comparing to the axle assembly of towed vehicles. Therefore, in practice, they have more frequent failures compared to the axle assemblies of towed vehicles. The parameters that are important for these assemblies are: the bearing capacity of the assembly, the appearance of microcracks in the elements of the axle assemblies, the contact profile of the wheel - rail [3], residual stresses after the process of forming the pressed assembly, etc.

Fig. 2. Axle assemblies of towed vehicles

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Regulations, International Union of Railways (UIC), give approximate values for these assemblies [4], while the details are defined by designers and technologists in the production of these assemblies. In the formation of the assembly, the influential parameters are: geometric characteristics (diameter, contact length and shape of contact surfaces), pressure on contact surfaces (force during realization of pressed assembly, inhomogeneity of component materials, material stiffness, variation of shape of contact surface, quality of machined surfaces, direction of propagation of contact surfaces unevenness), lubricant (machining method of contact surface, surface hardness, pressing speed, types of lubricants, surface roughness, surface cleanliness) and microclimate conditions. The characteristics of material are defined and, as a rule, there should not be any deviation from it [4,5,6,7]. The history of materials is kept throughout the service life of the components of the assembly, because in the event of a breakdown, it is obligatory to check it detailly in order to detect possible causes that led to the accident. The technological process of preparation and manufacture of assemblies is a secret and property of the manufacturer of the assembly.

2. BASIC PARAMETERS FOR PRODUCTION OF AN AXLE ASSEMBLY

When preparing the elements for the production of the axle assembly, in addition to the geometric preparation of the assembly elements, it is obligatory to control microcracks and various possible inclusions in the axle and the body of the wheels before machining and after machining. The control is performed by non-destructive methods. For the assembly, the approximate maximum and minimum values of geometric measures and pressing forces are prescribed by the standard UIC 813. Force used for forming assemblies for wheels of diameter ∅ 920 must be in the range of F = (555 ÷ 1100) kN. The approximate calculation of the allowed force is defined by equation

$$F = a \cdot D \; \left[kN\right] \tag{1}$$

where:

a - coefficient in a function of friction, ie. the types of lubricant used in pressing process,

D - diameter of the hub, mm.

As a lubricant in the formation of the assembly, it is recommended to use: flaxing oil or rapeseed oil, tallow and MoS_2, and a combination of oils and tallow. In order to achieve the force in the prescribed range, the following are very important: tolerances of the hole in the hub and the diameter of the shaft on which the hub rests, the centricity of the shaft and its ovality at the point of retraction of the wheel, roughness of contact surfaces, direction of propagation of the contact surfaces unevenness, lubricant properties, centricity and ovality of wheel hub openings and microprocessing of pressing technology. Positions of deviation of ovality and centricity of a hole and a shaft during pressing can significantly affect the force of the pressing regarding the same overlap sizes. Therefore, it is necessary to determine the directions of the position of the contact surfaces of the hole and the shaft during pressing as a function of ovality and centricity.

3. CARRING CAPACITY OF THE ASSEMBLY

Since axial and radial forces occur in operation of the axle assembly, as well as torques and dynamic shocks, the bearing capacity of the assembly is very important. The condition that the force and torque to which the pressed assembly is exposed in operation is less than the guaranteed bearing capacity of the assembly must be fulfilled.

The carring capacity of the assembly depends on the size of the contact surface, the size of the lap, the coefficient of adhesion and the contact pressure. For cylindrical contact surfaces it can be determined by the equation [8]

$$F = \frac{\pi \cdot l \cdot \mu \cdot z_p}{\xi_e + \xi_i} \cdot 10^{-4} \; \left[kN\right] \tag{2}$$

where:

l - contact surface length, cm

z_p - actual lap, μm

ξ_e, ξ_i - parameters of deformation of the outer and inner element of the assembly, cm^2/kN

μ- adhesion coefficient.

Equation (2) shows which elements affect the carrying capacity of the assembly, which is calculated theoretically. If the lap is larger and the roughness of the contact surfaces is lower, the carrying capacity of the assembly is higher. However, the actual carrying capacity differs from the theoretically calculated one and it changes when the assembly is in use, depending on: the dynamics of the motion of the pressed assembly, microclimate conditions, imbalance masses, etc. Due to safety, these assemblies must be constantly monitored during their use. Reliability parameters are achieved during the manufacture and maintenance of the axle assembly. The level of safety is affected by regular maintenance, and in order to increase that level, it is necessary to introduce modern monitoring methods for some parameters that can provide information about changes that may affect the safety of the operation of axle assemblies [8, 9]. This can be done by use of various sensors and digital technology which sends data to certain databases on the basis of which it is possible to obtain information on the safety of the use of the assembly [10]. In order to implement the modern monitoring methods, some material costs, which are not small, are required. However, the consequences of accidents can always be far expensive than investments in safety monitoring systems of vital elements of traction and towed railway vehicles.

4. EXPERIMENTAL RESEARCH

The goal of every user of certain systems and devices is that they perform their function without failure as long as possible. A longer period brings higher profits and reduces costs. For axle assemblies, it is known that the service life depends not only on the quality of their construction and maintenance, but also on: dynamics of motion, number of kilometers passed in loaded and unloaded condition, quality of railway infrastructure on which they move and quality of maintenance. The wheels of the axle assemblies have a shorter service life which in practice is about 5 to 10 years, depending on the quality of other contact elements and the number of kilometers passed. The axles may last much longer and user requirements are that their service life would be unlimited. In this research, axles aged 25 to 40 years were used, and the wheels were newly manufactured. During the research period, 40 axle assemblies for freight wagons were manufactured and assembled. During the production, all the elements that affect the value of the pressing force, which directly affect the bearing capacity of the assembly and its reliability, were monitored. MoS_2 was used for lubrication.

Other parameters of the process are defined within the regulations of UIC 813. Detection of pressing force was performed on a press that has a digital measuring chain (detects force and pressing path in a real time), Table 1. After processing axle assemblies, their control on compliance with UIC standards 813 was performed.

Tab. 1. Pressing force

No.	Difference of the lap [mm]	Pressing force [kN]		
		Wheel A	Wheel B	Difference
1	0.000	871	965	-94
2	0.050	973	826	147
3	0.030	1077	840	237
4	0.010	759	813	-54
5	0.020	1076	841	235
6	0.030	802	902	-100
7	0.020	980	923	57
8	0.020	985	882	103
9	0.000	773	905	-132
10	0.040	870	806	64
11	0.000	827	903	-76
12	-0.040	720	820	-100
13	0.000	762	792	-30
14	0.010	797	961	-164
15	-0.010	849	917	-68
16	-0.040	832	729	103
17	0.010	823	821	2
18	0.010	904	888	16
19	0.040	880	664	216
20	0.040	913	871	42
21	-0.030	857	909	-52
22	0.000	783	786	-3
23	0.020	833	709	124
24	0.000	888	775	113
25	0.070	755	768	-13
26	0.030	674	725	-51
27	-0.020	804	812	-8
28	0.020	932	759	173
29	-0.010	745	725	20
30	0.000	732	714	18
31	0.020	792	765	27
32	0.010	722	792	-70
33	0.000	771	699	72
34	0.020	865	782	83
35	0.020	747	905	-158
36	-0.010	743	803	-60
37	0.010	688	678	10
38	0.020	918	685	233
39	-0.010	768	697	71
40	0.000	752	965	-213

Pressing is achieved with a speed of 50 mm/min. The diagrams of the increase of the pressing force as a function of the contact length of the contact surfaces are given in Figure 3 and Figure 4.

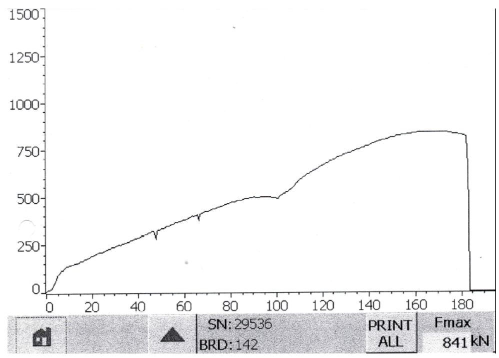

Fig. 3. Functional dependence of the pressing force on the contact length, different centricity and ovality (wheel B, smaller the lap, larger roughness, narrower tolerance of the cylindricality of the hub opening, number 5 in Table 1)

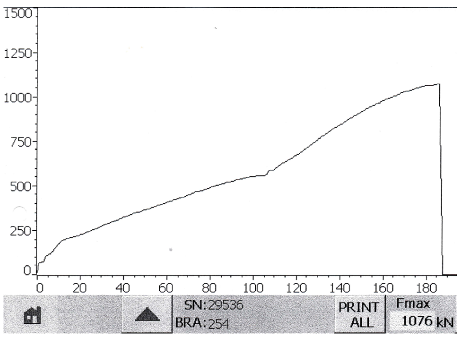

Fig. 4. Dependence of pressing force on contact length, equal centricity and ovality (wheel A, larger lap and lower roughness on the seat of the wheel hub)

3.1 Analysis of the causes of deviation of the pressing force

The difference in pressing force is up to 20% on the same shaft. There is a question what are the causes of this deviation. The causes of deviation are: the size of the overlap, the uniformity of the thickness of the layer of lubricant, the centricity and ovality of the surfaces forming the assembly, the height of the unevenness, ie. quality of machining surfaces. If the overlap is the same, then the intensity of the force is influenced by the technological parameters of the machinig of contact surfaces, the centricity and ovality of those surfaces. When the overlap is equal (on the left and right wheel) of the pressed shaft assembly, the pressing force can vary up to 10%, which is influenced by: roughness, centricity and ovality of the contact surfaces and the technological process of pressing. Since the quality of the material is defined by the UIC standard, the reliability of the assembly is influenced by the geometric and technological parameters of the preparation of the surfaces through which the assembly is realized and the pressing process itself. The maximum force applied in this research was 1077 kN and the minimum 664 kN. It can be stated that, in addition to the size of the overlap, the intensity of the force is significantly influenced by the centricity and ovality of the contact surfaces, their roughness and the direction of unevenness. If the roughness is higher, larger plastic deformations of the unevenness occur, which affects the pressing force. The pressing force is of lower intensity, which affects the bearing capacity of the assembly.

5. CONCLUSION

In order to bring the reliability of assemblies to a higher level, in addition to the tolerance of the dimensions of the assembly elements, it is necessary to pay significant attention to: the roughness of the contact surfaces, the shape and position of these surfaces and technological parameters. Since the length of the shaft is over 2000 mm, it is important the centricity of the contact surfaces be within the narrower limits during the assembling process, because if the deviations are higher, the pressing force exceeds the upper allowed limit. If this limit is exceeded, the assembly cannot go to further procedure. It can be concluded from this research that the deviations for approximately the same tolerance measures of pressing forces, which is relevant for the bearing capacity of the assembly, can vary up to 20%. The safety of the use of the assembly can be increased by modern monitoring methods of the assembly in operation and their quality maintenance. It has been realized that users do not have a database of the number of kilometers passed of axle assemblies in the loaded and unloaded state, which is very important due to the number of stress change cycles in the axle assemblies. When processing new assemblies with used axles, all non-destructive testing methods must be implemented in order to increase the level of reliability and safety. It is necessary to introduce modern monitoring methods of possible disturbances on these assemblies that may endanger the safety of the use of traction and towed vehicles in railway traffic. These methods need to be improved in order to increase the safety.

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XIX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
RAILCON '20

APPLICATION OF REVERSING OUTPUT DUAL BRAKE PLANETARY TRANSMISSIONS

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Abstract *– A transmission for internal combustion powered railway vehicles must be rugged and reliable. There are two categories of transmissions for the low to mid-high power range of railway vehicles: transmissions derived from ordinary highway truck or bus automatic transmissions and hydromechanical transmissions. Unlike steam locomotives, modern railway vehicles are expected to be capable of moving in both directions at the same speed, which is particularly important when units from the same series are connected together in multiple. Hydrodynamic and mechanical transmissions are known for use in these vehicles, but planetary gear trains are also suitable for the application due to their characteristics. An output planetary gearbox providing two equal transmission ratios, however with the output shaft rotating in different directions. Priority should be given to designs using clutch-type brakes for compactness and reliability, however band brakes should be considered if ease of maintenance is a priority. To sum up, the application of this design of planetary gearbox would simplify the design and manufacture of both hydrodynamic and mechanical transmissions for railway vehicles, which is the subject of the paper.*

Keywords – Railway vehicle, transmissions, planetary gear box

1. INTRODUCTION

Planetary gear trains (PGTs) offer numerous advantages when compared to conventional gear trains. Because of that, their use has been significantly expanded in a variety of applications in mechanical engineering. Examples of PGT applications at fishing boats and machine tools are shown in [1,2,3].

Their application is also possible at railway vehicles, as they are required to move both forwards and backwards with the same speed. Both hydrodynamic and PGT transmissions are commonplace in these vehicles, however reversing requires an additional mechanical stage. This stage can be easily replaced by an output planetary gearbox providing two equal transmission ratios, however with the output shaft rotating in different directions. Compound two-speed PGTs which are obtained from component planetary gear trains (stages) by linking shafts of different component planetary gear trains may be used in the design of such output gearboxes. Two speed PGTs are the subject of this paper and we shall consider two-speed two-carrier PGTs with four external shafts composed of two PGTs of the basic type.

The internal structures of compound gear trains are laid out. The significant number of all possible schemes requires a systematization of the variants, as well as their labelling.

The procedure of structure and important basic parameters determination is followed by a numerical example in which the optimal two-speed planetary gear train that meet predefined transmission requirements is selected, defined by the numbers of teeth of the central gears, modules and transmission ratios. The position of the transmission and working conditions of the railway vehicles determine the input data for the computer program that define structure and important parameters of the component planetary gear trains.

The basic part of the paper is the review of acceptable solutions of the transmission for the selected application by using a specially developed computer program. The choice between the program obtained variants is then made by comparative analysis of the solutions.

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2. PLANETARY GEAR BOXES

By connecting two shafts of one component PGT to two shafts of the other component PGT, a mechanism with four external shafts is obtained (Fig. 1). Among these four external shafts, two are coupled shafts and two are single external shafts. The component PGTs will be referred to as the component trains and the obtained mechanism with four external shafts will be referred to as the compound train. The two-component compound PGT is the simplest form of compound PGT

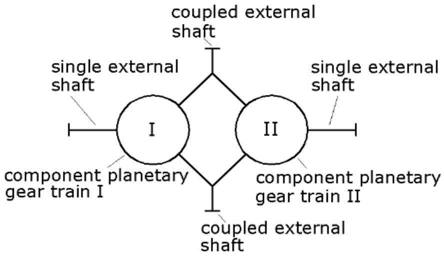


Fig. 1. Planetary gear train with four external shafts (compound train)

Both component trains are planetary gear trains of the basic type consisting of a sun gear 1, planet gear 2, ring gear 3 and planet carrier h, as shown in Fig. 2.

The simple and compound PGTs discussed in this paper will be described by means of Wolf-Arnaudov symbols (Figure 2) [1,3]. This is the most common type of PGT, and it has seen the broadest use in mechanics. It is most commonly used as a single stage transmission, or as a building block for higher compound planetary gear trains. Its primary advantage over other PGT types lies, first of all, in its efficiency. The overall dimensions and mass of this type of PGT are small, and its manufacturing costs are relatively low because of the relatively simple production process.

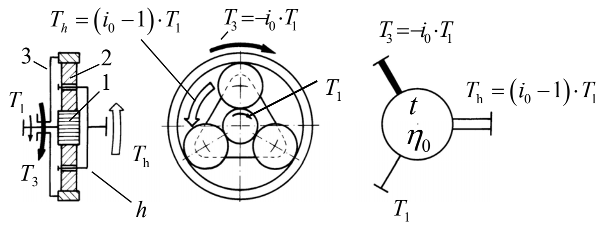


Fig. 2. Wolf-Arnaudov symbol and torque ratios of the basic type of PGT [4]

Planetary gear train shafts are loaded with torques as indicated in Fig. 2. The torque on the ring gear shaft T_3 and the torque on the carrier shaft T_h are given as functions of the ideal torque ratio t and the torque acting on the sun gear shaft T_1.

The ideal torque ratio is

$$t=\frac{T_3}{T_1}=\left|\frac{z_3}{z_1}\right|=-i_0>+1 \tag{1}$$

where i_0 is the basic transmission ratio, z_1 is the number of teeth of the sun gear and z_3 is the number of teeth of the ring gear.

Transmission ratio depends on locked element: sun gear, ring gear or carrier.

Two component trains can be joined in a total of 36 possible ways [5], however due to isomorphism, there are only 12 different ways which result in PGTs with four external shafts, Fig. 3.

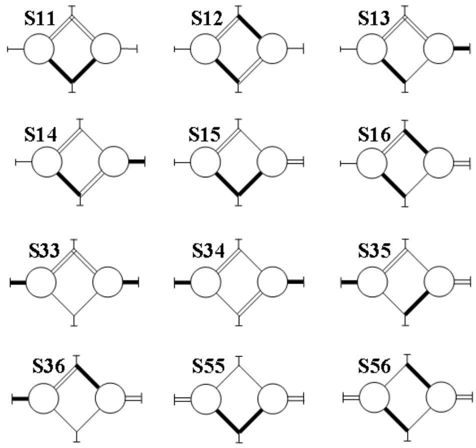


Fig. 3. Systematization of all schemes of two-carrier PGTs with four external shafts [1,6]

In every presented scheme it is possible to put brakes as well as the driving or the operating machine on external shafts in 12 different ways (V1…V12), which are referred to as the layout variants (Fig. 4). By placing brakes on different shafts it is possible to influence the power flow and kinematic characteristics. It is an important advantage, since these transmissions can be used as multiple-speed gearboxes.

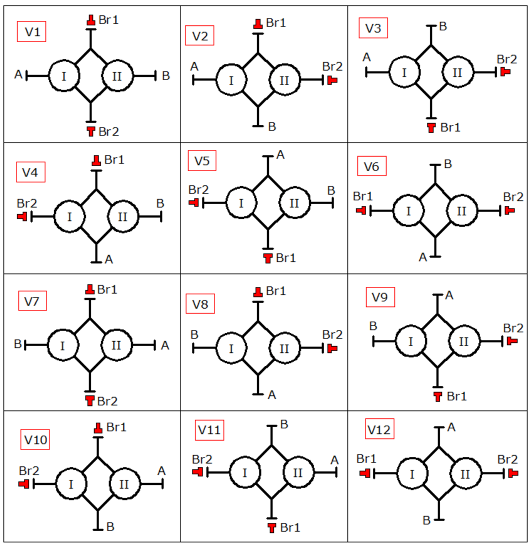


Fig. 4. Layout variants of two-carrier planetary gear trains with four external shafts [6,7]

3. NUMERICAL EXAMPLE AND DISCUSSION

A computer program *DVOBRZ* is based on a principle of synthesis of a two-speed PGTs [5]. It is used to select the optimal variant from similar multi-speed PGTs

The transmission ratio achieved by the activation of brake Br1 is marked as i_{Br1} and the transmission ratio realized by the activation of brake Br2 is marked as i_{Br2}, and all valid solutions are finally stored. The program is able to compare them according to the defined relevant criteria, e.g. minimal radial dimensions, maximum equivalent efficiency etc. [5].

A railway vehicle transmission will be used as a practical example for the selection of two-speed PGTs.

After taking into consideration that the required transmission ratios are i_1= -4.5 and i_2= 4.5, solutions have been found with transmission ratios in the ranges $-4,6 \le i_1 \le -4,4$ and $4,4 \le i_2 \le 4,6$. The important outher input datum is also frequency of working with transmission ratios: $\alpha_{i1}=0,5$ (50%) and $\alpha_{i2}=0,5$ (50%). The task is choice of optimal solution according to efficiency taking into consideration condition under which railway vehicle works. Based on the requirements and assumptions listed above, the *DVOBRZ* program lists six possible solutions for two-speed PGTs.

The main parameters are summarized in Table 1 while the kinematic schemes of acceptable solutions are shown in Table 2. The main parameters include the numbers of teeth of all gears and ideal torque ratios for both component gear trains. The number of planets is three exept bolded solution where the number of planets is four. The program *DVOBRZ* gives the ideal torque ratios for both gear trains. The tooth numbers of all gears were adopted on the basis of the ideal torque ratios [8], and presented in Table 1.

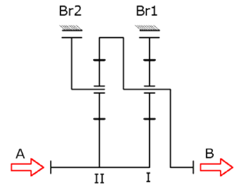
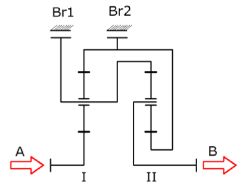
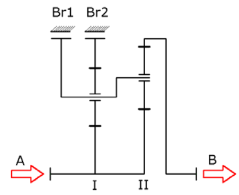
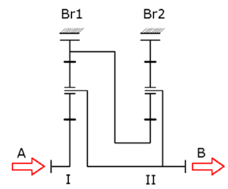
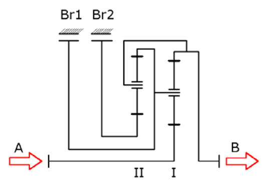
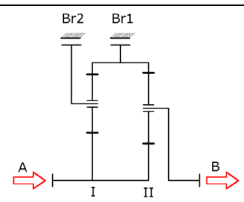
Tab. 1. Main parameters of both component gear trains

Mark	t_I	t_{II}	z_{1I}	z_{2I}	z_{3I}	z_{1II}	z_{2II}	z_{3II}
S36V6	3.5	4.555	14	17	49	**20**	**35**	**92**
S16V1	1.714	1.604	42	15	72	53	16	85
S33V4	1.714	4.437	42	15	72	16	27	71
S13V3	3.5	1.553	14	17	49	47	13	73
S12V2	4.55	1.553	20	35	91	47	13	73
S55V5	1.714	3.4	42	15	72	15	18	51

The tooth numbers respect the assembly conditions (conditions of coaxiality, adjacency and conjunction).

Kinematic diagrams of acceptable solutions are shown in the Tab. 2.

Tab. 2. Kinematic diagrams of acceptable solutions

No	Designation	Kinematic diagram
1.	S36V6	
2.	S16V1	
3.	S33V4	
4.	S13V3	
5.	S12V2	
6.	S55V5	

The transmission ratios and efficiencies have been calculated for all acceptable solutions in both cases: with brake Br1 active, and with brake Br2 active. The results are presented in Table 3.

The transmission ratio with active brake Br1 i_{Br1} and transmission ratio with active brake Br2 i_{Br2} are defined by using the adopted tooth number (Table 3). Also, the basic efficiency η_0 was calculated as a function of the tooth numbers of all gears [5, 9], and presented in Table 3.

The efficiency with active brake Br1 η_{Br1} and the efficiency with active brake Br2 η_{Br2} were calculated as a function of ideal torque ratios and basic efficiencies [5].

Tab. 3. Transmision ratios and efficiencies

Mark	i_{Br1}	i_{Br2}	η_{0I}	η_{0I}	η_{Br1}	η_{Br2}
S36V6	4,5	-4,55	0,973	0,985	0,979	0,985
S16V1	-4,464	4,407	0,976	0,978	0,962	0,976
S33V4	-4,438	4,422	0,976	0,980	0,980	0,959
S13V3	4,5	-4,436	0,973	0,973	0,979	0,934
S12V2	-4,55	4,573	0,985	0,973	0,985	0,969
S55V5	4,4	-4,475	0,976	0,974	0,980	0,924

All solutions provide the required transmission ratios and also present high efficiency values in both directions of output shaft rotation.

The optimal solution is then selected by the designer according to technological and economical demands, i.e. manufacturing costs.

This is achieved by analysis of kinematic diagrams, Tab. 2. Priority is given to a design which does not require drilled shafts, and this is achieved with layout S36V6. The power flow through this transmission solution is presented in Fig. 5 and in Fig. 6.

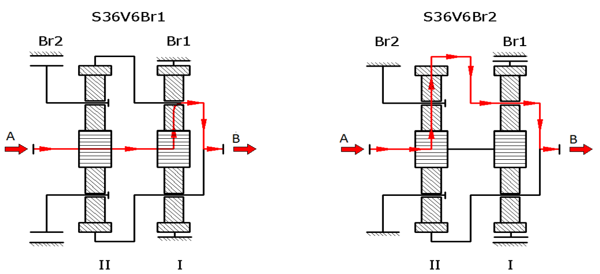


Fig. 5. Power flow through the transmission when the brake Br1 is activated (a) and when the brake Br2 is activated (b)

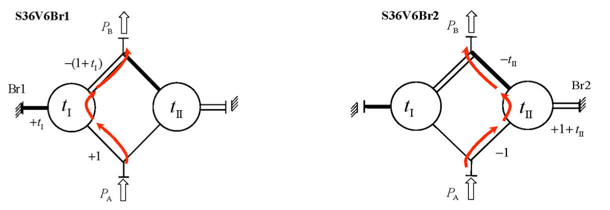


Fig. 6. Symbolic view with the power flow for solution S36V6: a) Br1 is activated, b) Br2 is activated

In this design. both brakes are acting on single external shafts. It is obvious that in both situations, i.e. by activating any brake, only one stage works is operational (two-shaft operating mode), while the other revolves idly. Because of that, power wastage occurs in only one PGT stage and there is only one power sink.

4. CONCLUSION

Two-speed planetary gear trains with four external shafts, composed of two simple planetary gear trains are presented in this paper, including a systematization of their kinematic structures and layout variants. Due to their characteristics, they are applicable in systems which require transmission ratio change under load.

This paper presents a quick determination of the structure and important basic parameters of two-speed planetary gear trains. This is enabled by using DVOBRZ, a computer program developed for examination of two-speed planetary gear trains. The procedure is followed by a numerical example dealing with the application to a railway vehicle where two directions of rotation at the same speed are necesary.

All possible schemes obtained by program are realized and main parameters are defined. The most appropriate scheme is chosen by analyzing obtained schemes according to technological demands.

ACKNOWLEDGEMENT

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THE MARKET CONCEPT OF RAILWAY VEHICLES MAINTENANCE ON THE RAILWAYS OF REPUBLIC OF SRPSKA

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Rade CVIJANOVIĆ[3]

Abstract *– The maintenance of railway vehicles is a combination of all management, administrative and technical activities during the service life of these vehicles with the aim of remaining in service or returning to service in a condition capable of performing the required functions. Apart from the technical, the railway system has been the subject of strong institutional development for the last two decades. The emergence of private railway companies, the application of new technologies and the development of new ways of organizing traffic further complicate the complexity of the railways. The complexity of the railway system requires the definition of clear responsibilities and obligations of all participants. All participants in the railway system must contribute to a higher level of safety and the development of the interoperability of the European railway network. The owner of the railway vehicle is responsible for maintaining the vehicle in the orderly condition. For freight cars, OTIF regulates (ATMF - Annex A) establishment of a competent maintenance body - ECM, where car maintenance is carried out through four functions. On the example of the Railways of Republic of Srpska, the maintenance system for all towing and towed vehicles was considered, and its compliance with the principles of the modern transport market was assessed.*

Keywords – railway vehicles, maintenance, transport market, interoperability.

1. INTRODUCTION

The policy and strategic goals of the European Union (EU) are based on a single and open transport market throughout the EU and Europe, and should be the path to a new concept of railways in Bosnia and Herzegovina, including the Railways of Republika Srpska (ZRS). In the new environmental conditions, a solution needs to be found that will satisfy the numerous specifics of the built railway systems of all countries and at the same time lead to the creation of preconditions for the single market. The aim of this paper is to present a model of the process of maintenance of railway vehicles based on the organizational structure of the ZRS, which satisfies the conditions of a market-oriented railway.

2. REGULATORY FRAMEWORK AND ESTABLISHMENT OF RAILWAY VEHICLE MAINTENANCE SYSTEMS

2.1. Certification of personnel for maintenance and technical inspection

For all towing and towed vehicles, certain maintenance workshops must be certified by the Notified Body - NOBO-s and entered in the national vehicle register. The certificate of fulfillment of conditions must meet the conditions necessary for the safe and orderly conduct of railway traffic. The overall goal of certification is to provide confidence to all road users that the maintenance system through maintenance management meets specific requirements and to guarantee railway undertakings that vehicle maintenance is performed by professionals [4].

The national railway safety authority issues a certificate to the person in charge of the maintenance of railway vehicles and keeps records of all issued certificates in the national register of railway vehicles.

The technical inspection of the vehicle in the process of issuing a license for the use of the vehicle serves to check whether the vehicle has the prescribed and correct devices and equipment installed and whether it is capable for safe traffic. The conditions and manner of performing technical inspections of towing and towed vehicles are mostly defined by railway undertakings within their safety management systems, although in some countries they are prescribed by the national railway safety authority.

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2.2. The rolling stock register

The rolling stock of railway companies in BiH, including ZRS, is stored in the central base managed by the European Railway Agency - ERA, so therefore, there are no obstacles for railway wagons from BiH to operate on the EU railway network as well as in the neighboring countries. Only authorized persons of the Regulatory Board and railway companies ZRS and Railways of the Federation of BiH have access to the database.

The National Railway Safety Authority, on the basis of instructions prescribed by the Intergovernmental Organization for International Railway Transport - OTIF, maintains a national register of railway vehicles and railway infrastructure. All national vehicle registers of EU member states are connected to the European vehicle register maintained by the European Railway Agency - ERA. The National Railway Safety Authority submits to the Secretary-General of OTIF all approved vehicle types on a given railway network. OTIF maintains a register of vehicle types of all Member States [4]. A good example of establishing a maintenance system is the maintenance of freight cars. Each body in charge of maintenance of freight cars must be certified by the ECM - Entities in Charge of Maintenance certification body, and the vehicle registered in the national vehicle register.

3. FUNCTIONS OF ZRS MAINTENANCE SYSTEM

The maintenance body performs the functions of managing the maintenance system and is responsible for the outcome of the maintenance activities it manages. Currently, the Railways of Republic of Srpska is a single company with inseparable infrastructure from railway operations and the company is sector-organized. Since ZRS currently exists as a single legal entity, the maintenance system is integrated into the joint venture.

In order to prove that the maintenance system in the current state of ZRS has been established, four functions of the maintenance system were analyzed and checked: maintenance management function, maintenance development function, rolling stock management function and maintenance performing function [1].

a) I Maintenance management function

The maintenance management function ensures the safe condition of towing and towed vehicles in the railway system. This function coordinates maintenance functions. Maintenance processes are defined in the Business Plan of ZRS (external contractors for the implementation of the maintenance function, distribution of work by workshops, distribution of responsibilities, distribution of staff, established strategies for achieving maintenance goals). Also, this function monitors maintenance and checks maintenance results. Practically, the maintenance decision-making process is controlled by the maintenance management.

b) II Maintenance development function

The maintenance development function includes the identification and management of all maintenance activities of railway vehicles that affect safety. This function manages the rolling stock maintenance file. Types of maintenance, regular maintenance cycles, as well as allowed deviations from the planned maintenance deadlines are defined for towing and towed vehicles.

c) III Rolling stock maintenance function

The management of the maintenance of the rolling stock of ZRS includes the exclusion of towing and towed vehicles from the traffic and their return to the traffic after the performed maintenance. This function ensures the timely maintenance of towing and towed vehicles.

d) IV Maintenance performing function

The function of performing maintenance is the technical performance of maintenance tasks of railway vehicles. At ZRS, the function of maintaining railway vehicles is performed in workshops in Doboj, Prijedor and Banja Luka. The document management system for the repair of freight cars is defined in the document Manual of the freight car maintenance system (No. 399-4 / 13 of 05.03.2013), based on which the Railways of Republika Srpska received a certificate for freight car maintenance according to ECM - Entity in Charge of Maintenance.

4. THE RAILWAYS OF REPUBLIC OF SRPSKA MAINTENANCE SYSTEM CONCEPT

According to the existing organization and technical-technological division of labor for the field of maintenance of railway rolling stock on the railway network of the Railways of Republic of Srpska, there are three locations:

1. Workshop Doboj - workshop for repairing locomotives and cars;
2. Workshop Banja Luka - workshop for repairing passenger cars;
3. Workshop Prijedor - workshop for repairing freight cars.

ZRS has adopted regulations on the maintenance of railway vehicles in an uniform manner (Rule book 241) which regulates the order and level of maintenance of all railway vehicles that enter the public railway lines. In addition, maintenance is performed according to applicable international regulations: COTIF, GCU, AVV, RID, UTP, UIC publications.

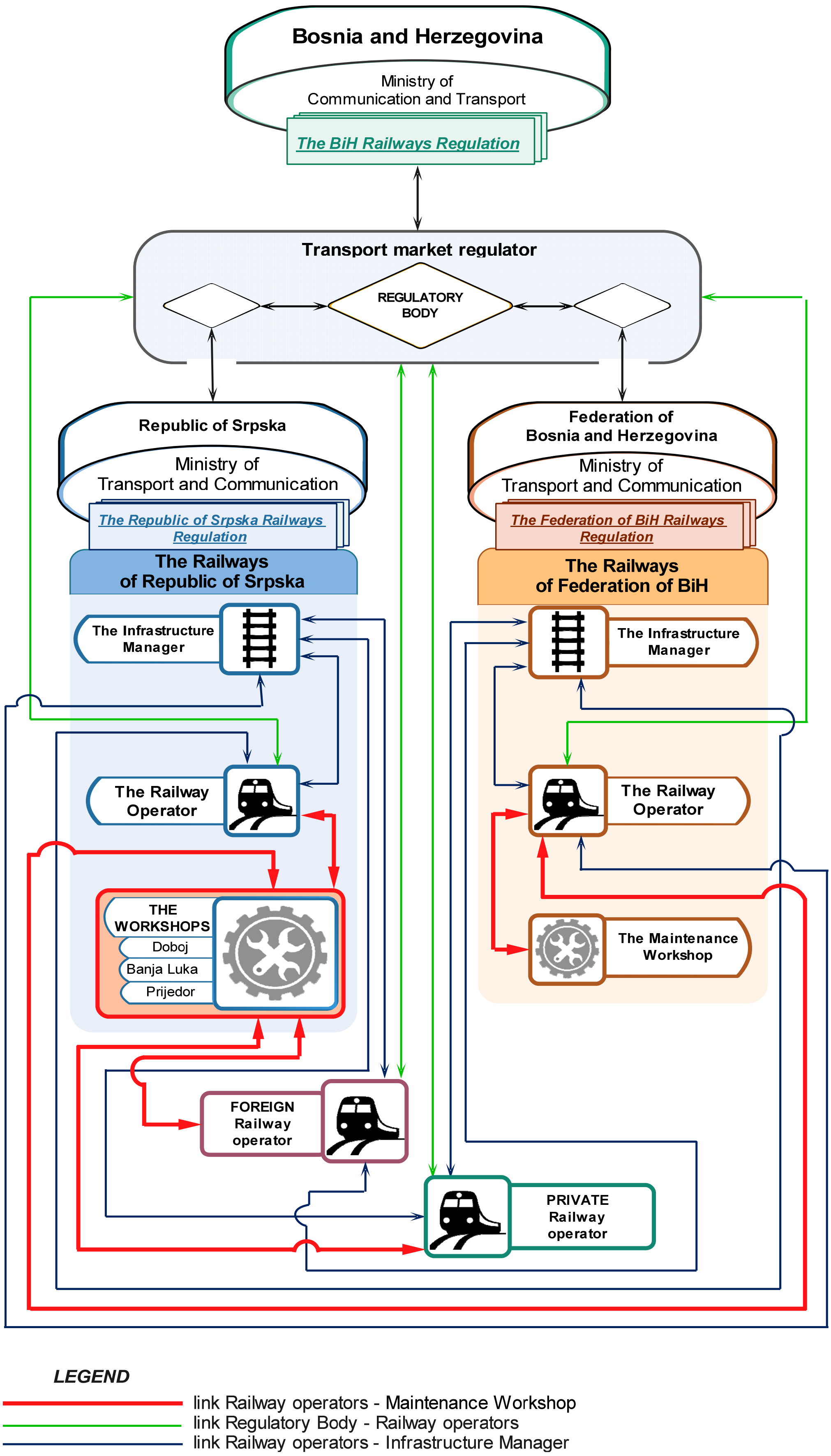

Fig.1. System of maintenance of ZRS in the conditions of open transport market

When handing over the railway vehicles for repair to the workshop, the technical condition of the vehicle is determined, as well as the missing and installed atypical parts, sets and equipment of the vehicle, which must be installed or replaced with appropriate standardized parts. The scope of work is prescribed for each type of repair, and the procedure for repairing the towing vehicle, sets and equipment is regulated by the appropriate technical instruction [6].

The level of competence of the ZRS railway vehicles maintenance system is considered through the following areas:

- Registration for performing activities and valid certificates of sections;
- Organization of work in the Sections for maintenance of railway vehicles;
- Document management system;
- System for monitoring the impact of maintenance on safety and reliability;
- Procurement system for spare parts, materials and maintenance services;
- Technological procedures;
- Professional qualification of employees;
- Infrastructural and technical equipment;
- Technical documentation;
- Measuring, testing and control equipment.

ZRS rolling stock maintenance workshops already have certificates for the performance of railway vehicle maintenance services issued by the Regulatory Board. Retaining the certificates of ZRS workshops, as well as all those from BiH, is a very important segment in opening the market of railway services. The current model of work organization in ZRS has classified the workshops for the maintenance of the rolling stock as a group of jobs of the railway operator, which must change by the time BiH joins the European Union [1].

Studying of the literature and experiences regarding the issue of maintenance of railway vehicles leads to the realization that there is no universal model or strategy for the maintenance of railway vehicles. Railway operators and vehicle owners determine the maintenance model based on the structure of their own rolling stock, the experience gained while using the vehicle and the applicable regulations. Taking into account the general concept of maintenance, basic principles, types, cycles and other maintenance procedures, as well as the principles of the open transport market, Fig. 1 presents the maintenance system of ZRS and the interactions of its participants.

5. CONCLUSION

The Railways of Republic of Srpska currently exists as a single legal entity and the maintenance system is integrated into the joint venture. Examination of the ZRS maintenance system indicates that it has been established for more than 200 years in accordance with its tradition and that it satisfies the basic principles of its functions. The entire railway system of ZRS in the coming period should be reformed and reoriented to the market way of doing business. The new organizational structure of the railways should make a turn in the domain: opening the transport market, user orientation, financial consolidation of the existing railways, increasing operational efficiency and reducing the number of employees while increasing their competence. The reform will also affect the maintenance system, and accordingly a set of recommendations has been made as a guideline for its improvement:

1. Harmonize the systematization of jobs with maintenance technology;
2. Fill vacancies with skilled labor (uncontrolled labor outflow);
3. Develop maintenance functions in accordance with the procedures of the International Organization for International Railway Transport (OTIF);
4. Develop a management function and a maintenance development function at the level of the maintenance section (free transport market);
5. Technically and technologically modernize the maintenance function.

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OPTIMIZATION OF THE SADDLE SUPPORT STRUCTURE OF THE FREIGHT WAGON TYPE SHIMMNS

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Abstract *– This paper presents the optimization process of the saddle support structure of the freight wagon type Shimmns intended for the transportation of the sheet coils using the Finite Element Method. Analysis of the information about the similar wagons and their behavior in exploitation, reveals that there are common characteristic critical areas where the initial cracks occurs, and those are the welded joints in saddle support structure. Due the existence of coil sheets with different dimensions, the whole range of coil sheets is modelled to cover all possible load cases in according to standards. Based on the results of the initial analysis, it is concluded that the greatest impact on the crack formation in the critical area has the fatigue of the material in welded zone caused by the cyclic fatigue loads in vertical direction. After the reason has been established, reconstruction was done in such a way that prevents the occurrence of the cracks on a new wagon. With reconstruction completed, new wagon with the modified support structure was analyzed in accordance with appropriate standards in the freight wagon industry for all of the load cases. Results with optimized support structure showed improvement, especially of stress reduction in critical areas.*

Keywords – Optimization, FEM, Freight Wagon, Fatigue, Coil Sheet

1. INTRODUCTION

The Shimmns wagons are used for transportation of the metal sheet coils (primarily steel), which can have different diameter, width, and subsequently mass, as well as different placement on the wagon saddles, therefore a wagon must be able to withstand a wide range of load cases set by the International Union of Railways (UIC). Particular standards used are TSI [1] and BS EN 12663-2 [2].

Numerical analysis for 134 load cases, according to standards [1] and [2] was performed using the Finite Element Method (FEM) [3]. FEMAP software [4] is used as pre and post-processor for the FEM mesh generation and display of the results. FEM analysis itself was done using NX Nastran solver, which is built in FEMAP. The initial results show that for all of the static load cases, wagon satisfies safety criteria, i.e. maximum calculated stresses are lower than permissible stress. However, according to Eurocode 3 [5], in order to insure fatigue strength for important structural segments, permissible stress is reduced using the scale factor for safe life, and for some load cases, there are small areas of the wagon structure that have stress concentration above permissible limit, those spots are located in the characteristic welds of the saddle support structure. By analyzing similar wagons of the same type from other manufacturers and collecting the information about their behavior in exploitation, it is confirmed that these are common characteristic critical areas where the initial crack occurs.

Detail modelling of these zones is conducted, including mesh convergence testing in several iterations. Optimization performed in FEMAP reduces stresses in these areas, and the proposed modifications ensures safety in exploitation with minimal and cost effective changes in the wagon design.

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2. THE SHIMMNS WAGON MODEL

A technical description of four-axle bogie wagon type Shimmns is given in [6]. The wagon is designed for transportation of sheets coils that are loaded in the horizontal position onto five cradles. Transported coils need to be protected from weather conditions as it can be seen in the Fig. 1.

Fig.1. Partially uncovered Shimmns wagon

The main characteristics of the Shimmns wagon, according to [6] are given in Tab. 1.

Tab. 1. Technical data of wagon type Shimmns

Track width	1435mm
Gauge	TSI G1
Number of wheelsets	4
Length over buffers	12040mm
Central bolts distance between	7000mm
Load opening width	2400mm
Wagon height from the rail	~4275mm
Tare weight	22t±2%
Max. cargo weight	68t
Max. axle load	22.5t
Max. speed (empry/loaded)	120/100km/h
Bogie type	Y25 Lsi(f) - C
The smallest curve radius	35m

Technical drawing, and FEM model of Shimmns wagon are shown in Fig. 2. and Fig. 3. respectively.

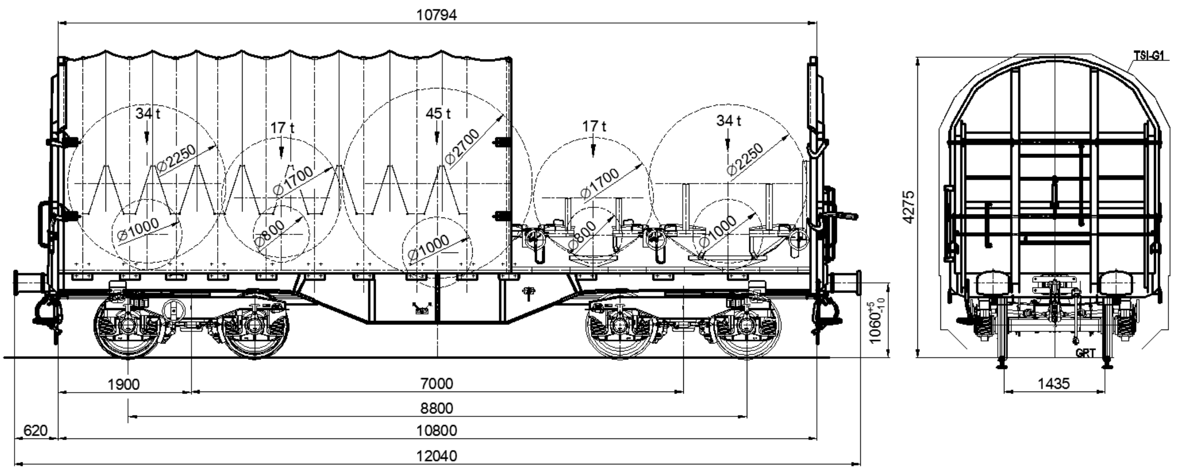

Fig.2. Technical drawing of Shimmns wagon

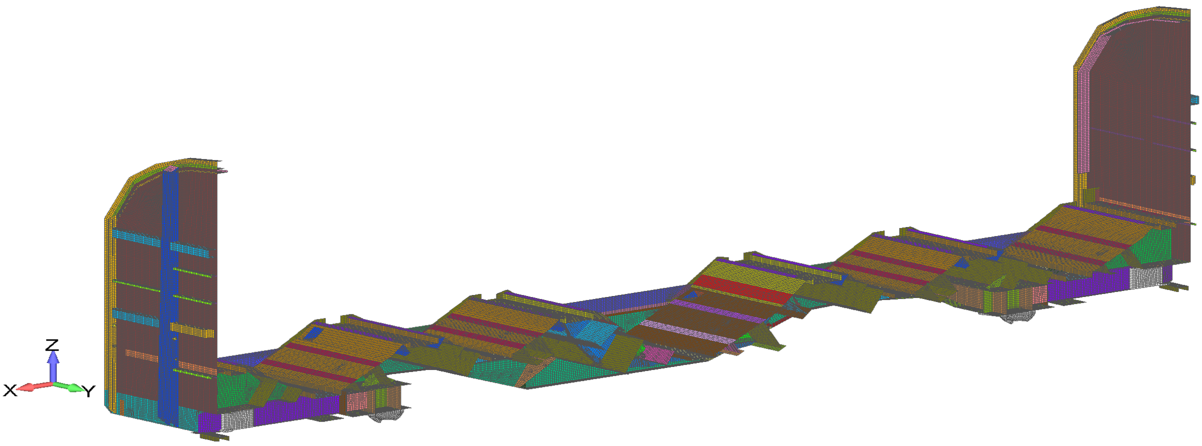

Fig.3. FEM model of Shimmns wagon

The FEM model is used to analyze wagon support structure, and does not include bogies, cover and other additional elements, which are represented in the model as loads and constraints. Due to symmetry, one half of the wagon is modeled in FEM. Shell elements of the appropriate thickness and 3D elements (for modeling of support elements) were used for creating the finite element mesh. The structure is modeled in details with 212991 elements and 218890 nodes and within the calculation there is a system of about one million and three hundred thousand equations being solved. General element side length is about 20 mm, with local mesh refinement in area of interest, (Fig. 4).

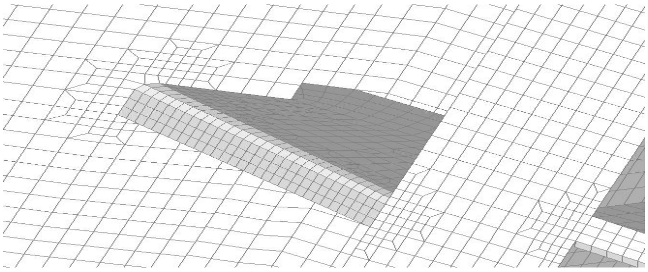

Fig.4. Mesh refinement around welded joints

The wagon is made of steel S355J2+N [6], with the following characteristics, shown in Tab. 2.

Tab. 2. S355J2+N material characteristics

Physical Characteristics		
E [N/mm^2]	ρ [kg/mm^3]	ν
$2.10 \cdot 10^5$	$7.85 \cdot 10^{-6}$	0.3
Mechanical Characteristics		
R_e [N/mm^2]	R_m [N/mm^2]	KV [J][1]
355	490-630	27

The Table 3 shows range of diameters and weight of the steel coils for each cradle [5].

Tab. 3. Maximum loading of the cradle and dimensions of the steel coils

Cradle no.	**Coil diameter** [mm]	**Load** [t]
1	1000 – 2250	34
2	800 – 1700	17
3	1000 – 2700	45
4	800 – 1700	17
5	1000 – 2250	34

Total weight of steel coils that one wagon can carry is 68 tons (see Tab. 1.) and this weight can be attained using the combination of different diameter and width of the coils shown in Tab. 3.

[1] *KV – material fracture toughness at -20°C*

Not all combinations are simulated, instead the focus was on boundary cases with the maximum width or maximum diameter of coils as it is assumed they are most critical. For these extremes, we analyzed different combination of coil size and placement, examples of some considered load cases are shown in Fig. 5 and Fig. 6.

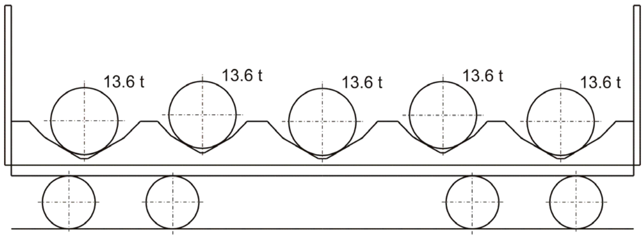

Fig.5. Evenly distributed load on all 5 cradles

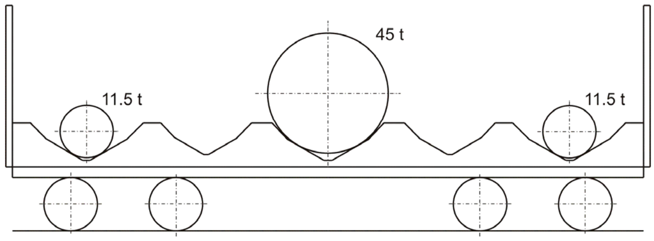

Fig.6. Big coil in the middle. smaller on front and back cradle

These are just 2 examples of the vertical load scenarios, which are analyzed for both maximum width and maximum diameter cases. The final report also includes longitudinal load cases for buffers and the coupling areas, lifting, jacking, as well as load combinations and service fatigue loads. In total 134 load cases were analyzed, and since the initial shape failed to meet safety criteria for some load cases, several iterations were made until final design was obtained.

These changes were performed using engineering experience and FEM analysis in FEMAP, adopting the different design approaches, adding the reinforcement ribs, for example.

3. OPTIMIZATION USING FEMAP AND EXPERIENCE

3 types of optimization are shown in Fig. 7.

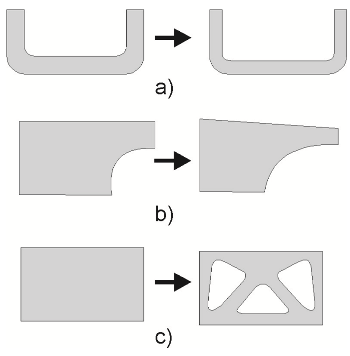

Fig.7. Different optimization types: a) parametric; b) shape; c) topology

Parametric optimization changes only properties of the structures while the geometry remains the same, this primarily means changing the plate thickness until the stress is reduced below permissible levels [1]. This optimization improved overall behavior of wagon for certain load cases, however, dynamic loads, such are buffing test and loading, create stress concentration in small areas, that needed to be addressed differently.

Shape optimization changes dimensions and layout of existing features, and it is more complex since it requires changes in FEM mesh, so it's usually done only when necessary. We used the shape optimization for the wagon design to alleviate the stress concentration.

Topology optimization implies the creation of the new features, mostly free shape openings for even stress distribution, but in this case, added features are strengthening ribs and plates.

4. OPTIMIZATION RESULTS

In this section we will show design improvements and stress reduction achieved by the optimization. In Fig. 8. the actual crack on a wagon in exploitation is shown. FEM model of the initial design is shown in Fig. 9., and the new optimized model in Fig. 10. Von Misses stress for the vertical load shown in Fig. 5., for central saddle support structure, viewed from below the wagon is shown in Fig. 9. and Fig. 10.

Fig.8. Crack in the welded joint on the actual wagon

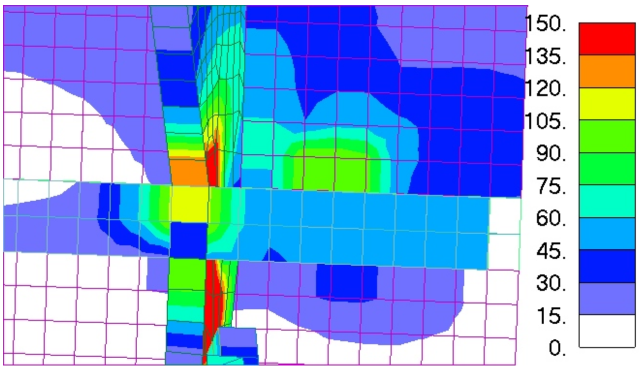

Fig.9. Stress concentration in the initial model

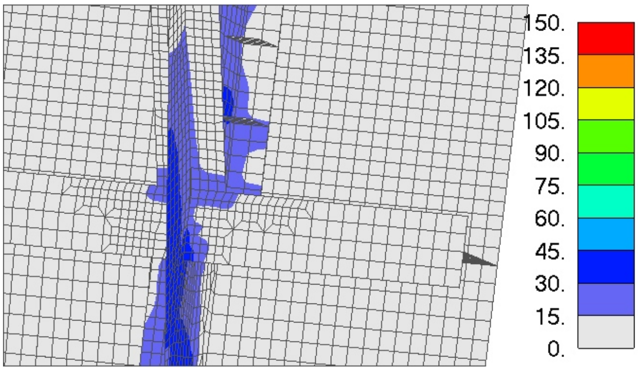

Fig.10. Stress reduction in the optimized design

As it can be seen from Fig. 10., mesh needed to be refined, U profile bar (bottom of Fig. 8. and Fig. 9.) was removed, and strengthening ribs were added in the final model.

5. CONCLUSION

The purpose of this paper is to demonstrate the methodology used for the analysis of fatigue crack formation, and reconstruction of wagon structure which will prevent recurrence of the cracks in the refurbished wagons, and to make the new wagons impervious to cracks. The analysis was conducted for 134 load cases, according to the standards defined in [1],[2] and during the process of design improvement, several iterations of mesh refinement and geometry changes were made resulting in an optimized wagon which satisfy all safety criteria and is more resilient to fatigue crack formation.

ACKNOWLEDGEMENT

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RELIABILITY COMPARISON OF CLASSICAL BRAKE FOR FREIGHT WAGONS AND THE INTEGRATED BOGIE BRAKE TYPE IBB 10

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Dragan MILČIČ[3]

Abstract *– The introduction of integrated (compact) bogie brake systems has opened a new chapter of improvements in freight wagon performance, efficiency, reliability, reduction of weight and noise, simpler installation, reduction of installation space, lower operating costs, reduced maintenance, increased reliability availability and safety. Because of all these benefits from using integrated bogie brake systems, many producers of railway brake equipment have developed their own compact brake systems. In this paper will be described a reliability comparison of classical (conventional) brake system for freight wagons and the integrated bogie brake system type IBB 10 from the railway brake equipment producer Wabtec.*

Keywords – railway, reliability, bogie, brake, freight, wagon

1. INTRODUCTION

As freight operators focus on the need for greater improvements in efficiency and safety, there is a significant need for advances in wagon brake systems. The use of integrated bogie brake systems is allowing freight operators and maintainers to benefit from higher network capacity and reduced maintenance costs. These advanced bogie brake systems that include integrated brake cylinder, slack adjusters and parking hand brake are adding to these benefits through additional capacity improvements, significant safety improvements for operators and maintainers and optimized life cycle costs [1].

The aim of this paper is to make direct comparison of classical (conventional) bogie brake and the integrated bogie brake type IBB 10 in terms of efficiency, weight difference brake shoe (block) wearing and reliability.

2. CLASSICAL BRAKE FOR FREIGHT WAGONS

The most common classical (conventional) brake system for freight wagons (excluding all of the pneumatic units), consists of one brake cylinder, one slack adjuster, pull rods, brake riggings, brake triangles, hangers, brake shoe holders and brake shoes. The description of the classical brake system is shown in fig. 1 and the schematic view of this system is shown in fig. 2

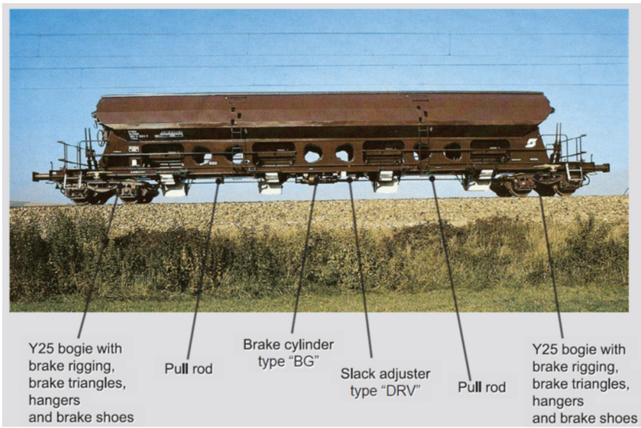

Fig.1. Description of classical brake system

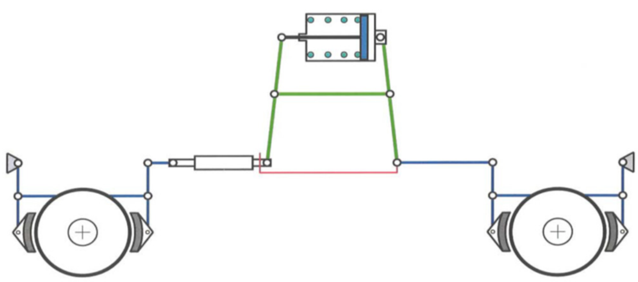

Fig.2. Schematic view of classical brake system

The simplicity of the classical brake system has

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made this brake equipment dominant in the freight market worldwide until the arrival of integrated bogie brake systems.

3. INTEGRATED BOGIE BRAKE SYSTEM TYPE IBB 10

The patented integrated bogie brake type IBB 10 was developed for freight wagon application. It is the lightest brake on the railway market so far [2].

The invention in general relates to the area of braking devices for railway vehicles, and regards especially to bogie brake devices and slack adjusters for the use with bogie brake devices. Braking devices are used for the realization of braking of railway vehicles by introducing of air under pressure into the relevant cylinder chamber. Through a system of levers and slack adjusters the created force in the brake cylinder is intensified and transferred directly onto the wheels of the bogie [3].

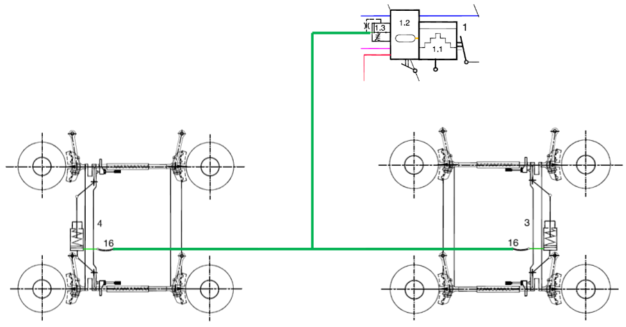

Fig.3. Schematic view of integrated bogie brake system

This design enables easy assembly and disassembly of each component separately, which is a big advantage taking into consideration overhauling and maintenance of the system. The assembly of IBB 10 is located between the bogie wheels and it fits the standard interfaces of Y25 bogie family. Its function is to provide equal braking force application simultaneously on four wheels. The design is based on the use of a brake cylinder as an executive unit with (or without) hand brake application and two double-acting slack adjusters for automatic gap regulation between all four wheels and brake shoes [2]. The air pressure in the brake cylinder creates a force which is intensified and transferred to the slack adjusters by levers, and equal force is transmitted to the primary and secondary beam from which the brake shoe holders apply the braking force on the wheels through brake shoes (blocks).

On one bogie can be assembled one IBB 10, and because the most common variant is one wagon to have two bogies, usually total of two IBB 10 are needed per wagon as a set. Because each wagon needs to have the function to be parked in stationary position when it is removed from the train composition, at least one IBB 10 needs to have a parking hand brake. Because of different types of wagons, two types of hand brake systems were developed by Wabtec MZT - platform hand brake (when the activation is done from the platform of the wagon) and side hand brake (which is assembled on the bogie and activated from lateral side of the wagon).

On fig. 4 is shown the integrated bogie brake type IBB 10 without hand brake.

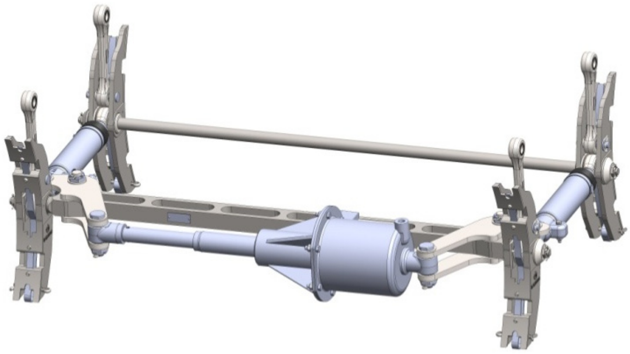

Fig.4. IBB 10 without hand brake

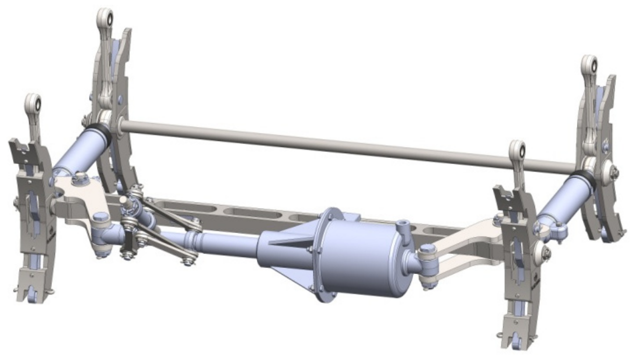

Fig.5. IBB 10 with platform hand brake

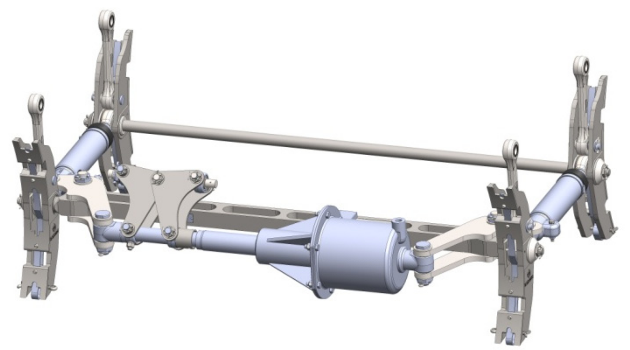

Fig.6. IBB 10 with side hand brake

On fig. 5 is shown the integrated bogie brake type IBB 10 with platform hand brake. It has the same function as IBB 10 without hand brake with addition of manual hand brake application from the platform of the wagon. The platform hand brake mechanism should be connected with telescope cardan shaft and hand wheel, which is operated from the platform of the wagon from longitudinal direction. The hand brake activation is realized by rotation of the hand wheel and this torque is transferred onto the spindle of the hand brake mechanism by the telescope cardan shaft. The hand brake mechanism consists of system of levers which activate the brake cylinder by rotation of the hand brake spindle. With the activation of the brake cylinder the braking function occurs just like in service braking.

On Fig. 6 is shown the integrated bogie brake type IBB 10 with side hand brake. It is very similar with IBB 10 with platform hand brake, with only difference that the hand brake application is realized from the ground and from the lateral sides of the bogie. Because the hand brake activation needs to be operated from each side of the wagon, a gearbox needs to be installed on the body of the bogie, which will cause the hand brake application to be realized by rotation of the hand wheel in the same direction from both sides (usually rotation in clockwise direction). The hand wheels from each side need to be connected to the gearbox and in the same time connected to the spindle of the side hand brake mechanism with telescope cardan shaft.

4. RELIABILITY COMPARISON OF CLASSICAL BRAKE AND IBB 10

One of most important benefits of the integrated bogie brake design is its higher reliability level. In order to be evaluated reliability of both brake systems and have better perceptions it is necessary both systems to be analysed through reliability block diagrams. On Fig.7 is presented reliability block diagram of conventional brake system. Cumulated reliability of the system is presented with blocks which depending of mutual interdependencies are in serial connection. Because of it calculation will be made by multiplication of their values and result will be cumulative reliability of the system.

$$R = R_{DV} \cdot R_{DVb} \cdot R_{BC} \cdot R_{SA} \cdot R_{mech} \tag{1}$$

R_{DV} – reliability of distributor valve
R_{DVb} – reliability of distributor valve bracket
R_{BC} – reliability of brake cylinder
R_{SA} – reliability of slack adjuster
R_{mech} – reliability of mechanism

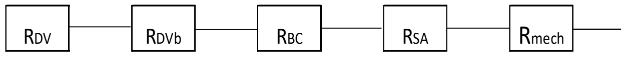

Fig.7. Reliability block diagram of conventional brake system

On the second figure (Fig. 8) is presented reliability block diagram of integrated bogie brake system. As can be seen the first two blocks are in serial connection while in the following part arises separation of two mutually independent reliability blocks. This blocks in reality are the two independent IBB10 mechanism. The equitation for calculation the reliability for blocks is shown on the figure. To get better picture it is necessary to make assumption that reliability is equally allocated to all blocks of the system and is 95% than in the first case on conventional system achieved reliability will be approximately15% lower than reliability in second case with IBB brake mechanism. That indicate that the second system has higher level of inherent reliability level due to design of the system [4],[5]. The other advantage of the integrated bogie brake design compared with classical design is that which prevent wagon to loose complete braking power if one IBB systems is in failure. This means that the other will stay in function beside the fact that wagon will lose 50% of braking power. In case with classical system if only one executive block lose function than complete system lose function and wagon loses 100% braking power.

$$R = R_{DV} \cdot R_{DVb} \cdot \big(1 - (1 - R_{IBB1}) \cdot (1 - R_{IBB2})\big)$$
$$= R_{IBB1} = R_{IBB2} = R_{BC} \cdot \big(1 - (1 - R_{SA}) \cdot (1 - R_{SA})\big) \cdot R_{mech} \tag{2}$$

R_{DV} – reliability of distributor valve
R_{DVb} – reliability of distributor valve bracket
R_{BC} – reliability of brake cylinder
R_{SA} – reliability of slack adjuster
R_{mech} – reliability of mechanism
R_{IBB} – reliability of IBB mechanism

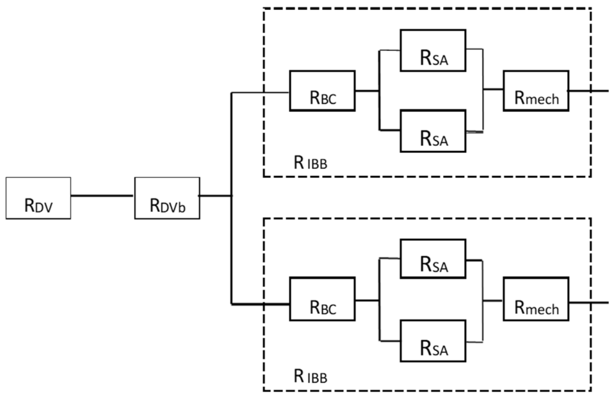

Fig.8. Reliability block diagram of integrated bogie brake system

5. CONCLUSION

From all of the above mentioned and analysis made from different viewpoints can be concluded that new design of braking systems with integrated bogie brake have a lot of advantages compared to classical braking systems. These advantages will have positive impact on wagon efficiency in terms of additional capacity of freight wagon, better maintainability, optimized life cycle costs, and better reliability availability and safety.

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Strategy and Policy

XIX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
RAILCON '20

DETERMINING THE RISK ACCEPTANCE CRITERIA FOR OPERATIONAL CHANGES IN THE RAILWAY SYSTEM USING THE "SAFETY II" PRINCIPLE

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Dušan STAMENKOVIĆ[3]

Abstract *– One of the key elements of any risk assessment procedure is the definition of the Risk Acceptance Criteria (RAC), often based on the so-called "historical records", ie. statistical data and reports from the previous period of the system operation. Given the essential but also the legal-formal significance of this criterion, its value must be very reliably determined. The railway system is very complex, so despite the large number of statistical data that are usually collected on the railway, we often do not have indicators that directly relate to the part of the system that we certify. Therefore, it is necessary to choose from the available data those that best assess its level of security. Another problem is that the criterion of risk acceptability must be determined on the basis of events that have a relatively low frequency but can have very severe consequences (collisions, slips, etc.). In such cases, even relatively small deviations in the period from which we will take data or types of indicators can drastically affect the value of this criterion. In addition, in practice, more detailed data for a longer period of time (over 10-15 years) are often not available. In order to solve these problems, in this paper the principle of the so-called Safety II concept was applied, which, unlike the traditional approach (so-called Safety I), is not based only on the analysis of unsuccessful events (accidents, incidents), which are relatively few, but also on analysis of successful events, of which there are far more. In this way, the database of the considered data is far expanded and can better reflect the actual level of security achieved in the previous level. The problem with this approach is that traditionally detailed records are kept mainly of unsuccessful events that caused the consequences, while for a large number of activities implemented without problems usually do not have special statistical records, so it is necessary to collect this data in another way. In this paper, this method is applied to define the risk acceptance criteria for on board obstacle detection and track intrusion system that could provide support or replace the driver in the process of railway traffic automation.*

Keywords – Railway safety, Certification, Risk Acceptance Criteria, Safety level

1. INTRODUCTION

Risk assessment is one of the most important elements of certification and authorization of technical, operational and organizational parts of the railway system in the European regulatory framework.

Application of procedure of risk assessment and the method of its implementation is described in a number of EU directives and regulations that regulate this system. Before the enactment of this regulation, ie. before the creation of the common railway market in the EU, risk assessment was mostly a part of engineering and cost-benefit analysis and studies. However, its inclusion into a legal regulative has led to additional demands for implementation of that procedure, because it explicitly questions the compliance with legal conditions and legal responsibility. This is especially relevant in the field of automatic train operation, because without human factor in the process of train control, main legal responsibility in case of accidents during the driving (that are possible even in the most ideal conditions), shifts onto the area of certification and authorization of automatic train control systems.

One of the key elements of every risk assessment procedure, especially with regards to compliance with

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legal conditions, is the definition of RAC - Risk Acceptance Criteria. European regulative in the railway sector does not define the accurate way of determining these criteria, so in practice, general principles from the field of risk assessment are used. Before long, it turned out that this leaves the room for different interpretations of what exactly is a legally acceptable risk, and what is its exact level[1],[2]. Several works from that period outlined the need to describe risk acceptance more accurately. However, this is still not the case, except partially for risk acceptance criteria for technical systems. In practice, there are two methods for defining this criterium:

- based on historical evidence derived from an analysis of statistical data about previous safety performance;
- based on safety system goals that are defined beforehand (project based).

In practice, these criteria are far more commonly defined using the first method[3]. EU Safety Directive 2016/798 in its preamble (5), clause 1 prescribes maintaining the current level of safety as one of its main conditions. Having that in mind, even when risk assessment criteria are project based, it is necessary to compare the expected safety level with the previous one, which represents the minimal necessary risk acceptance criteria. Many works and studies support this conclusion. The first comprehensive study related to european regulative for safety management and interoperability of railway system states the following: „Acceptability of risk should be based on ensuring that at least the same level of safety performance is maintained and every reasonably practicable improvement has been made before the change is implemented“ [4] .

This principle of defining the risk acceptance criteria is practically corresponding to GAME (Globalement au moins équivalent) principle: "Any change to an existing system, and the design and manufacture of a new system, must be carried out in such a way that the resulting global level of safety is at least equivalent to as existing systems that are in use." GAME risk acceptance criteria defining principle is legally binding in French railway sector, but is also commonly used in other areas. Based on this, it is possible to conclude that defining the current safety level as a minimal risk acceptance criteria is one of the most important steps in the process of certification and authorization of new railway systems.

2. DETERMINING AND QUANTIFYING THE EXISTING SAFETY LEVEL

Regardless of the significance of this term, especially with regards to regulation compliance and legal responsibility, there are no common rules and norms for determining and quantifying the achieved (or preferred) safety level. National reference values for common safety goals are the exception. Common safety goals represent safety levels that must at least be reached by different parts of the rail system and by the system as a whole, expressed in risk acceptance criteria. Achievement of these goals is assessed through National reference values (NRV).

NRV are reference measures that quantify the existing (reached) level of safety in EU member countries[5]. They are determined as pondered average value of indicators in total and relative number for a period of 6 years using the formula:

$$NRV_Y = \frac{\sum_{i=x}^{N} W_i \times OBS_i}{\sum_{i=x}^{N} W_i} \qquad (1)$$

where W_i is ponder that represents the inverse absolute value of difference between yearly OBS_i indicator values, and their average value for a period of 6 years (N). Indicators for which NRV is calculated are number of accidents, number of incidents, number of injured persons, and amount of damage from accidents and incidents. Apart from Common Safety Goals, existing safety level is often used for defining the corporate safety goals within the safety management system or maintainance system of the infrastructure managers, railway undertakers or entitys in charge of maintenance.

By analyzing these documents, it is possible to conclude that the existing safety level within these systems is almost always quantified using average values of statistical data about dangerous events (accidents and incidents) in a certain period. Average value is most commonly calculated as a simple arithmetic mean value, that is expressed in relative number of these events relative to the train or gross tonne kilometres. Time periods for which the values are calculated are usually between 5 and 10 years. This way of determining and quantifying existing safety level can be adequate for the safety goals that the EU railway agency (ERA) considers global, or for high level risk acceptance criteria (Figure 1) [3].

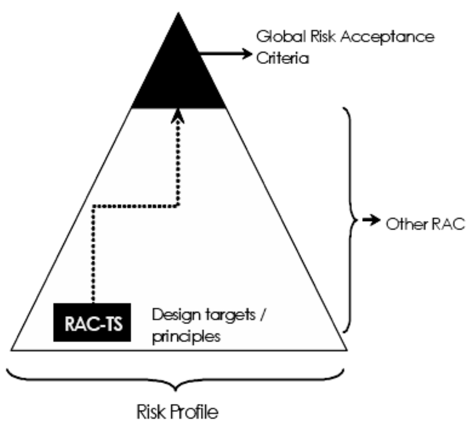

Fig.1. Hierarchy of Risk acceptance Criteria

However, when subjects of authorization and certification are parts of subsystems, or specific areas, other or technical level criteria are relevant (on functional level, hazard level, procedural level or equipment level). In these cases, the method of determining existing safety level in a way that is usual for safety goals (using the average value of unusual events or their consequences during a period of 5-10 years) may be inadequate. One of the reasons for this is that the railway system is very complex, so even with the large amount of statistical data that is usually collected, we do not have the indicators that are directly linked to the part of the system that is certified ie. whose correlation with the safety level specific for the observed part is not great. Second problem is that the safety level must be determined using the events that have relatively low frequency, but can have very serious consequences (collisions, derailment etc.) or can appear regularly in series.

In such cases, even the relatively small deviations in the observed period or the type of indicators can significantly impact the value of this criteria. Possible solution to this problem is the application of the principles of Safety II concept. This concept was developed, and has found its application in more complex systems, such as health systems and flight control. While the traditional approach, Safety I concept, is based on analysis of unsuccessful events (accidents, incidents), and their consequences, Safety II concept is based on analysis of all the events, both successful and unsuccessful. The First concept defines safety as the condition where the number of adverse outcomes (e.g., accidents, incidents and near misses) is as low as possible.

Safety-I is achieved by trying to make sure that things do not go wrong. The Second concept defines safety as a condition where the number of acceptable outcomes is as high as possible. Safety-II is achieved by trying to make sure that things go right, rather than by preventing them from going wrong[6]. When it comes to analyzing data, the main difference between these two concepts is that the first one is only focused on a few exceptional events, while the second one takes into consideration all of the events, and therefore has a wider base (figure 2.) Apart from that, these two concepts are also different in their approach to risk evaluation. While Safety I concept is focused on dangers and incidents, Safety II regards the risk as the state in which management and control of process is difficult[7].

3. QUANTIFYING EXISTING SAFETY LEVEL AS RISK ACCEPTANCE CRITERIUM FOR AUTOMATIC OBSTACLE DETECTION SYSTEM

In accordance with the classical approach, ie. Safety I concept, existing safety level for automatic obstacle detection system would be defined based on statistical data about accidents and incidents in which the train ran into immovable objects (not counting running into people and vehicles on railway crossings). The relevant data for IŽS a.d. railway network in the 2019 - 2020 time period is shown in table 1. It is expressed as the number of these events per milion driving kilometers. As can be seen, values for the year of 2017 deviate significantly when compared to the values for other years, and the difference between minimal and maximal value is around 8,7 times. Depending on the time period that we select for determining the existing safety level, and the way that we calculate average value, we could calculate that acceptable risk level is between 0,41 and 0,71 events per milion driving kilometers.

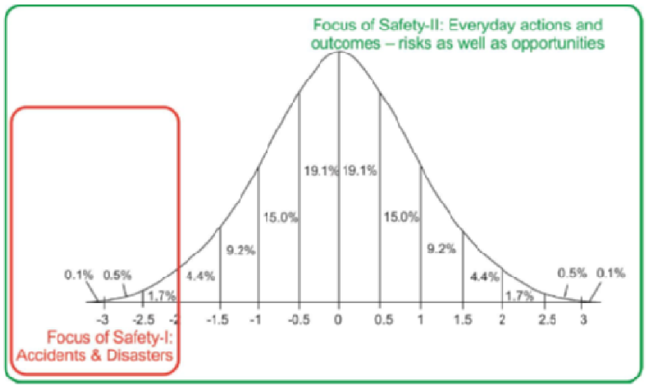

Fig 2. Area of data analysis in Safety I and II concepts

Tab 1. Number of train collisions with obstacles on the IŽS network

year	number of collisions on mil. tkm
2019	0,52
2018	0,33
2017	1,82
2016	0,62
2015	0,70
2014	0,27
2013	0,21
2012	0,78
2011	0,40
2012	0,44

Not only is this range too great for the needs of equipment certification and authorization, but all of these events are not unsuccessful events when seen from the obstacle detection system aspect. In most of the cases, the event in question could not be avoided in any way because of the current conditions (low visibility, short interval between the event and the approach of the train, and similar), but the reaction in a timely manner led to the maximal possible decrease of the consequences of the event. If we apply the Safety II concept, and analyze all events that include an immovable obstacle on the tracks, whether the train ran into it, or it was avoided, and base our risk analysis on the conditions that led to the event, we can get the results shown in table 2. In this case, different time intervals and ways of calculating the average value of the percentages of successful train driver reaction are not significant, since we get a very small range, from 94,5 to 94,95 percent.

Tab 2. total number of occurrences of obstacles on the IŽS network and the number of unsuccessful reactions of train drivers

year	total number of obstacles	nuber of unsuccessful driver reaction	success rate
2019	14	1	92,9
2018	6	0	100
2017	32	3	90,6
2016	18	1	94,4
2015	25	1	96,0
2014	29	2	93,1
2013	18	1	94,4
2012	28	0	100
2011	13	1	92,3
2010	33	2	93,9

Average value of this indicator for the entire 10 year period would be 94,76% of success rate, and could be used as a good evaluation of existing safety level for detection of immovable objects on tracks, and could be adopted as a minimal criteria for certification of automatic obstacle detection systems.

4. CONCLUSION

Determining the achieved level of safety as a minimum criterion of risk acceptance in the process of certification and authorization of new systems on the railway requires great precision and reliability. the traditional way of determining and quantifying it through indicators of accidents and incidents is often not good enough. Applying the Safety II concept, which analyzes all system-relevant events, both successful and unsuccessful, can give a much better result.

ACKNOWLEDGEMENT

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XIX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS RAILCON '20

MULTICRITERIA APPROACH FOR PSO SERVICES SELECTION IN RAIL SECTOR

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Abstract *– In the Law on Railways of the Republic of Serbia, the minimum criteria for PSO service are defined. However, there is a limited budget for PSO services in rail sector. Consequently, there is a need to select the rail services which will become PSO services. How to select these services, which method to apply, which criteria are relevant – are the questions considered in this paper. Authors proposed the TOPSIS method for the PSO services ranking. The set of relevant criteria are defined, as well. It is assumed that the budget for rail PSO services is limited, so the final rail PSO services selection, including this constraint, is made with Excel Solver.*

Keywords – Public Service Obligation, Railway services, Railway service quality, TOPSIS.

1. INTRODUCTION

The costs of passenger transport by rail cannot be covered only through revenues from tickets sold, which is why these services are economically unprofitable and subject to state subventions through a public transport obligation contract (PSO). However, certain restrictions are defined as well, ie the amount allocated from the budget for PSO trains is limited.

The whole process of defining PSO services can be observed through two steps: 1) first step - to determine whether a certain service should be realized through PSO (selection of potential PSO services); 2) second step - due to the limited budget, ranking the services that were selected in the first step as potential PSO services.

In this paper, the algorithm for the first step will be presented, and then, a multicriteria model for ranking PSO services will be developed. After the ranking list of PSO services is formed, and the amount for financing these services is defined, it is possible to present the final list of railway services that will be realized as PSO.

This paper is organized as follows. After the Introduction, in Section 2, the algorithm for potential PSO services in rail transport in Serbia is presented. In Section 3, the MCDM model for PSO services ranking in rail sector is developed. The last Section presents conclusions and future research directions.

2. ALGORITHM FOR PSO SERVICE SELECTION IN RAILWAY TRANSPORT

From the point of view of the community (Law on Railways, Article 111), the criteria on the basis of which the PSO should be determined are defined. Those are:

- The existance of common interest,
- Availability of other transportation modes,
- Costs of replacing railway transport with another transport mode and
- Qualitative and quantitative potential of railway undertakers.

The existence of a common interest is defined on the basis of travel generation. Travel generation involves determining the scope of travel that begins or ends in the observed zone, city or region, depending on the set of residential, economic and/or socio-economic characteristics of the observed zone [1].

In order to determine the existence of a common interest in more detail for certain trips, it is necessary to perform a travel distribution. Since in the previous step the number of trips that each zone emits or attracts on the observed lines was determined, it is now necessary to determine the passenger flow between pairs of zones (regions), ie between sources and destinations. The table defined in this way is called the O-D matrix. Growth factor models or gravitational models are most often used to define the O-D matrix.

In the next step, it is necessary to determine the availability of other modes of transport. When researching services and lines in railway traffic, first of all, the availability of road transport, as a competitive transport mode, should be investigated. This refers to the research of the availability of both public road transport, as well as the availability of private

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passenger cars and the possibility of their use.

If the previous step determined that there is a choice between several modes of transport, in the next step it is necessary to perform travel distribution by mode of transport. Models that predict the distribution between types are often called modal-split models and are used to allocate the total number of trips, across all pairs of the O-D matrix, to all available transport modes.

The calculation of the cost of replacing the railway transport with another transport mode should provide an answer to what extent is justified to maintain the PSO on railway instead of switching to alternative modes of transport. It should be keep in mind that the result of this analysis does not have to be explicit, but it is necessary to consider different scenarios, when abandonment of railway transport is fully financially justified, and when it is only partially justified or not at all.

Finally, it is necessary to determine whether the railway undertaking is able to meet the requirements of the requested service. It is necessary to determine whether the operator has a sufficient number of vehicles of the required type, as well as the required number of staff with the required qualifications, to be able to meet the PSO, in terms of frequency and quality of transport on the required lines. If the PSO were awarded by tendering, this step would be redundant, assuming that only the applications of those operators that could meet all the requirments would be considered correct applications.

In order to provide a safe and attractive service, with maximum quality, and increase the share of railways in passenger traffic, and with a limited budget to finance PSO railway services, it is necessary to select PSO services for financing and implementation.

Figure 1 shows the algorithm for determining the justification of PSO service request for the specified transport service in rail passenger transport.

3. MCDM MODEL FOR PSO SERVICES SELECTION IN RAIL SECTOR

3.1 Quality of service in public passenger transport

European standard EN13816 [2] defines the requirements for defining, determining and measuring the quality of service in public passenger transport (PPT), and provides guidance for the selection of the appropriate measurement method. The aim of this standard is to provide quality public transport and to bring the users' needs and expectations in focus.

The EN13816 standard is based on the concept of a service quality loop, which is shown in the Figure 2.

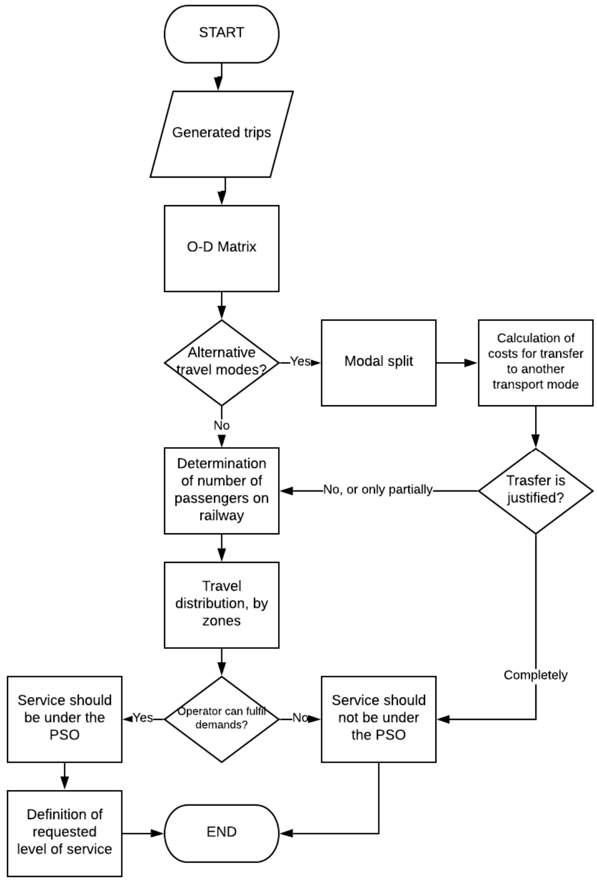

Fig. 1. Algorithm for determining the justification of PSO service request

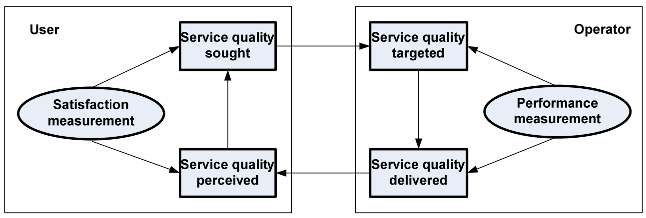

Fig. 2. Service quality loop (source: EN13816)

For efficient and effective service provision, it is necessary to apply the service production according to marketing business orientation - research the market first, ie. research the needs and expectations of users, and only then produce services that are consistent with the research results. This approach reduces or even eliminates the divergence between the realized or obtained quality and the required quality. Consequently, the satisfaction index of users is maximal. The smaller the divergence between the obtained and required quality, the greater the degree of satisfaction, and vice versa, the greater the difference, the smaller the satisfaction.

In accordance with the European standard EN13816 and the concept of service production accordinf to marketing business orientation, a multi-criteria model for ranking OJP trains has been proposed.

3.2 MCDM model for ranking rail PSO services

For selection of the rail PSO services with a constraint of limited budget, authors developed Multi-criteria decision making (MCDM) model. MCDM approach is proposed since there are heterogeneous and conflicting criteria in the model. The authors proposed TOPSIS method. Hwang and Yoon developed TOPSIS (*Technique for Order of Preference by Similarity to Ideal Solution*) in 1981 [3].

TOPSIS has numerous advantages, such as:

- Traditional and widely used method
- Easy to understand and apply
- Ability to analyze numerous alternatives (no limit)
- Ability to analyze different type of criteria (cost or benefit type)

However, due to the lack of real data, authors will present only elements of the model in this paper, without equations and calculations. The researchers or decision makers in their own research/analyze can apply any MCDM method or approach, not only TOPSIS.

Alternatives in the model are the potential rail PSO services. For each alternative (each PSO train) is necessary to define values of proposed **criteria** (criteria are the performances of a rail service).

In the Table 1 7 criteria are given. Each criterion should have its own weight: w_i, i=1,…,7, $\sum_{i=1}^{7} w_i = 1$. Decision maker defines the criteria weights. For PSO services the decision maker is a ministry in charge, in our country Ministry of construction, transport and infrastructure.

Performance measurement and passengers' satisfaction with rail services need to be carried out, and European standard EN 13816 provides the recommendations related to the suitable approaches for this kind of measurements and which quality attributes of public transport services should be considered.

The values of criteria listed in Table 1, railway operator should prepare and forward to the ministry in charge. In Serbia, that is "Srbija Voz" as the only railway company registered for passenger transport.

The values of sub-criteria, i.e. quality attributes of rail service, relevant for the satisfaction index measurement (Table 2), should be defined after the survey conduction. The respondents are rail passengers, i.e. actual users of rail services in Serbia.

After the survey, all data should be analyzed and the final satisfaction index with certain rail service can be measured. This output – the satisfaction index, is one of the 7 input, in fact the last criterion, in the MCDM model.

European Commission (EC) conducted a survey "European's satisfaction with rail services" in 2013 and 2018 [4]. In accordance with European standard EN 13816 and this EC survey, the quality attributes of rail service are proposed (Table 2). In developed model, the last criterion K_7 is the satisfaction index, and it can be defined based on those selected relevant quality attributes of rail service.

Tab.1. Model criteria

No.	Criteria	Unit	Type
K_1	Transportation costs	RSD	Min
K_2	Number of passengers during the last 5 years	/	Max
K_3	Growth of passenger demand (changes in the number of passengers during the last 5 years)	%	Max
K_4	The dominant reason for the trip	1-5*	Max
K_5	Is there some other mode of transport on the route?	1-4**	Min
K_6	Number of complaints for the rail service during the last year	/	Min
K_7	Satisfaction index	0-1	Max

*5-work and school; 4-business trip; 3-touristic; 2-leisure activities; 1-other.

**1-no other mode of transport; 2-there is other mode of transport, but rail is better solution; 3- there is other mode of transport, and rail is not so good solution; 4-there is other mode of transport, and it is much better than rail.

The output of the TOPSIS method are relative importances for each alternative. Based on these values, but with a limited budget, the set of chosen alternatives should be defined so the sum of relative alternatives' importances is the maximum. This can be done relatively easy with Excel Solver.

Tab. 2. Quality attributes of rail service

No.	Sub-criteria
$K_{7.1}$	Punctuality and reliability
$K_{7.2}$	Frequency of trains
$K_{7.3}$	Safety
$K_{7.4}$	Helpfulness and attitude of the staff on board the train
$K_{7.5}$	Cleanliness
$K_{7.6}$	Easy connection with other modes of transport
$K_{7.7}$	Availability of information about the train (especially about train delays)
$K_{7.8}$	Availability of information in the train (during the travel), especially about train delays

4. CONCLUSION

This paper presents the process of defining the final list of railway services that could be requested as PSO. This process is presented through two steps: selection of PSO services and ranking of PSO services. Railway services that meet all requests for PSO are entering the ranking process. After the ranking, list of PSO services has been made, and the final set of PSO services can be defined in accordance with the budget limitations.

The presented model is useful for a decision maker who should select the rail PSO service when the budget is limited. Decision maker is the ministry in charge, i.e. Ministry of construction, transport and infrastructure in Serbia.

The further research will be dedicated to the development the MCDM model for rail PSO services ranking in the presence of uncertainty and imprecision in the data.

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XIX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS RAILCON '20

USING MULTIPLE CRITERIA DECISION-MAKING TECHNIQUE TO EVALUATE SERBIAN RAILWAY SYSTEM OPERATION PERFORMANCE

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***Abstract** – Freight and passenger railway system operation performance evaluation results are important for government, operators and passengers. In this paper will be used one of the best known Multiple Criteria Decision-Making (MCDM) technique to evaluate the freight and passenger rail system's operation performance. Firstly, the authors will establish the evaluation indicator system based on official data with 5 indicators and a total of 18 sub-indicators to the freight transport as well as passenger transport. These operational data will be used as the input of the approach. Second, formulated approach to obtain the performance evaluation: the Entropy Weight Method (EWM) will be used to calculate the weight of each sub-indicator; and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) Method will be used to calculate the comprehensive evaluation values and rankings of performance for each year. Third, the Serbian railway with 6 years initial data will be chosen as the case study to test approach, the related suggestions to the freight transport as well as passenger transport will also be given.*

Keywords – Railway, Entropy-TOPSIS method, Operation performance evaluation

1. INTRODUCTION

In the 21st century, there is an awareness of the need for balanced transport development in the EU as well as the encouragement of environmentally friendly transport modes such as rail and inland waterway transport. The development of the railway was one of the best indicators of the country's economic development. About 80% of the railway network was located in the territories of the most developed countries in the world in the first half of the 20th century. However, although rail transport is the most environmentally friendly and energy efficient mode of transport, the volume of freight transport by rail is declining.

Observing all modes of transport in 2018, relative to 2017, it can be noted that increased activity was recorded in all transport modes, except in railway. As regarding passenger transport, the increase was recorded if related with 2013 in all transport modes except railway. Referring to freight transport, the increase was recorded when compared with 2013 in all transport modes, excluding inland waterway transport [1].

The main advantage of the railway is the ability to transport large quantities of goods and people over long distances. From the moment of loading of goods or boarding of passengers, the railway enables the transport of large capacities at high speeds. That is why this transport mode is efficient in areas of high population density or for large amounts of cargo, primarily agricultural products and industrial raw materials.

The railway is a complex system specialized in providing transport services. The railway system has the structure, organization, employees, equipment (infrastructure) and work technology. Railways apply a modern organizational theory based on a multidisciplinary approach (systemic approach to organization, multidimensional level model, dynamic character of the process, stochastic model of discrete events, system adaptability). Many tasks are routine because they are based on experience (processes are already programmed, planned and have procedures) and are realized hierarchically and finally decision-making is centralized. Management (of company) monitors the entire system and makes adjustments that

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require monitoring of operation efficiency based on available data.

The simplest approach to conceptualise and measure railway operation efficiency is by deriving key performance indicators (KPIs) from published data [2]. This can be sufficient to develop a simple but balanced scorecard. To monitor performance, both cross-sectional indicators (that compare systems) and time series indicators (that measure change over time) are needed. Capturing the full complexity of factors determining railway efficiency would require a very large dataset. This is not easily available and would be subject to inherent limitations regarding data quality. It is all very well and good to define and measure efficiency (however approximately) but the effort expended in defining, collecting and reporting data will have no payoff if there is nothing that can be done to change railway performance. One way to change efficiency, much favoured by traditional, engineering-dominated railway managements, is increased investment (increasing capital intensity) [2].

From a government perspective, evaluation of the railways operation performance is important because of the existence a basis for government subvention, and differences in performance between different evaluation periods are a strong justification for government financial subvention. Also, the results provide important references to the government on how to optimize and improve railway structures.

From an operator's perspective, evaluation of the railways operation performance can be seen as an efficiency assessment that focuses on whether operators are achieving pre-set goals and what jobs they have done to achieve the goals.

From the passenger perspective, evaluation of the railways operation performance can be considered as accessibility to meet the needs of travel, time saving and environmental friendliness, so that their efficiency can be measured by service use, service quality and service satisfaction.

Based on valid statistical data for the railway system of the Republic of Serbia, both for passenger and freight transport in the time frame from 2013 to 2018, the paper evaluates operation performance using Entropy method for determining weight coefficients and TOPSIS method for ranking the observed years.

In this paper, after a given introductory section which discusses about importance and performance analysis of the railways to the economy of a country and the users of its services, the second chapter is devoted to a review of the literature on the application of methodologies and approaches for evaluating the performance of rail transport. In the third chapter, sets of input data for passenger and freight rail transport are established. The fourth chapter gives a brief overview of the methods used to calculate the weighting coefficients and to rank the operation performance of rail transport in the Republic of Serbia for a certain time interval and to present the obtained results. At the end of the paper, the main conclusions and an overview of future research tasks will be presented.

2. LITERATURE REVIEW

When reviewing the literature about railway performance analysis, it is seen that in a limited number there are studies that use different decision-making methods with multiple criteria to obtain an assessment of railway transport efficiency. There are several approaches to measuring and evaluating railway performance. On the one hand, parametric approaches are very rarely used because they need certain assumptions to establish the desired function, while on the other hand researchers prefer to use nonparametric approaches that involve fewer assumptions [3].

Based on searches in the Scopus and Science Direct databases, various MCDM techniques are used to measure and evaluate performance in railway traffic such as AHP (Analytical Hierarchy Process), ANP (Analytical Network Process), TOPSIS, DEMATEL (Decision making trial and evaluation laboratory), VIKOR (VIše Kriterijumska Optimizacija Kompromisno Rešenje), etc. Also, the use of the DEA (Data Envelopment Analysis) method can be found in different areas of the railway [4]. This method was used alone or in combination with MCDM methods.

Yu (2008) used the DEA method to conduct an efficiency and effectiveness study for a group of 40 large railway systems (passenger and freight) in 2002 [5]. In [6] the authors used the DEA method to evaluate the efficiency of European railway companies, taking into account different input and output configurations. Although companies from Western Europe showed higher performance than companies from Central and Eastern Europe in terms of passenger and overall transport, this was not the case with freight transport.

The operation performance evaluation of the urban railway system in the Chinese city – Chengdu during 34 months using the Entropy – TOPSIS methods was performed in [7].

3. INPUT DATA

Indicators are frequently defined as quantitative measures that can be used "to illustrate and communicate complex phenomena simply, including trends and progress over time" [8]. Indicators can perform different functions. Collected information can be made suitable for analysis by those involved in decision-making and thus contribute to making better decisions.

In the conducted analysis were used available data collected by regular monthly, quarterly and annual statistical reports of transport enterprises („Serbia Train“ a.d., „Serbia Cargo“ a.d., “Combined transport“ d.o.o., Despotija. d.o.o. and „Infrastructure of Serbian railways“ a.d.) and were taken from [9]. Table 1 shows the 5 indicators and 18 sub-indicators used to assess the performance of passenger and freight railway transport. The basic indicators that used are Basic indicators of railway transport, Employees in railway transport, Generating power of railway transport, Consumption of fuel and electricity in transport and Railway asset.

4. THE APPROACH, CASE STUDY AND RESULTS DISCUSSIONS: THE SERBIAN RAILWAY

In order to make a good decision, it is necessary to specify alternatives by defining appropriate criteria. It is also necessary to define the weighting coefficients for each criterion ie the importance of each criterion in relation to the others. The weight coefficients are numbers that can be obtained by any of the following methods (Eigenvector method, Least squares weight method, Entropy method, etc.).

Tab.1. Indicators and sub-indicators of railway transport

Indicator	Sub-indicator	Specification of each sub-indicator	Unit of each sub-indicator
Basic indicators of rail transport	f_1	Passenger transport (locomotive km)	train km, thous.
	f_2	Freight transport (locomotive km)	train km, thous.
	f_3	Passenger transport	gross-ton km, mill.
	f_4	Passenger transport	gross-ton km, mill.
	f_5	Number of transported passengers	thous.
	f_6	Realized pkm	passenger-kilometers, thous.
	f_7	Quantity of goods transported	thous. t
	f_8	Realized tkm	ton-km, thous.
Employees in rail transport	f_9	-	number
Generating power of rail transport	f_{10}	Internal-combustion engines	kW, thous.
	f_{11}	Electric engines	kW, thous.
Consumption of fuel and electri-city in rail trans.	f_{12}	Liquid fuels	thous. t
	f_{13}	Electricity	thous. MWh
Railway asset	f_{14}	Effective length of tracks	km
	f_{15}	Passenger wagon stock and motor trains	number
	f_{16}		seats thous.
	f_{17}	Freight wagon stock	number
	f_{18}		tons of carrying capacity, thous.

Determining the objective weights of criteria according to the Entropy method is based on measuring the uncertainty of information contained in the decision matrix and directly generates a set of weight values of criteria based on the contrast of individual criteria values of alternatives for each criterion and then simultaneously for all criteria [10].

In 1981, Hwang and Yoon developed the TOPSIS method. The basic concept of the TOPSIS method is that the chosen alternative should have the smallest distance from the ideal solution and the largest distance from the negative ideal solution, in the geometric sense. During normalization, the transformation of minimization into maximization criteria is not performed. For each alternative, the distance from the ideal and negative ideal solution is calculated in relation to each criterion, taking into account the criteria that are minimized and maximized. The weight/significance of each alternative is finally determined based on the relative closeness of the alternatives to the ideal solution [11].

Based on the adopted indicators, for both passenger (Tab. 2) and freight transport (Tab. 3), evaluation operation performance of the Serbian railway was done by Entropy method for determining weight coefficients and the TOPSIS method for ranking the observed years.

The calculation results of weighting coefficients show in both passenger and freight rail transport: Employees in rail transport (0.1883) and the Generating power of rail transport - Internal-combustion engines (0.2010) are the two most important indicator (sub-indicator) in the evaluation system. Railway asset – Effective length of tracks has the smallest weighting coefficient for both passenger (0.0002) and freight (0.0003) rail transport and shows that this indicator has minor importance in the operation performance evaluation process. By ranking with TOPSIS method on the basic of adopted indicators for passenger transport of the Serbian railways in the time frame from 2013 to 2018, it can be seen that the best operation performances were in 2016, while in 2018 they recorded the worst case scenario (Tab. 2). When it comes to the obtained results for freight transport of the Serbian railways by ranking the appropriate indicators, it can be concluded that the operation performance since the beginning of the observed period in 2013 has improved and the best performance is expressed in 2018 (Tab. 3).

5. CONCLUSION

Increasingly modern rail transport provides a more convenient and cheaper way of daily transport of passengers and goods, so that the support of the state is necessary. It is important to set operational goals in advance and optimize the allocation of resources. In this paper, the evaluation of the railway operation efficiency in the Republic of Serbia is performing based on data collected by regular statistical reports of traffic business entities, with those help are form of which two sets of indicators for: passenger and freight

Tab.2. Passenger railway transport – indicators, weighting coefficients and ranking

	f_1	f_3	f_5	f_6	f_9	f_{10}	f_{11}	f_{12}	f_{13}	f_{14}	f_{15}	f_{16}	Rank
w_i	0.1293	0.0194	0.0378	0.1177	0.1883	0.2010	0.0451	0.0158	0.0373	0.0002	0.0746	0.1335	
2013	11531	1745	7158	612	18047	190	626	9	148	3819	786	48	**3**
2014	11170	1666	6443	452	17078	180	626	9	139	3819	748	45	**5**
2015	16256	1624	6258	509	16622	153	605	10	136	3766	833	56	**2**
2016	10930	1957	6092	438	13641	191	687	10	120	3766	883	59	**1**
2017	16644	1529	5638	377	10229	129	585	10	116	3764	691	48	**4**
2018	10417	1727	5062	347	10207	89	462	11	110	3752	542	30	**6**

Tab.3. Freight railway transport – indicators, weighting coefficients and ranking

	f_2	f_4	f_7	f_8	f_9	f_{10}	f_{11}	f_{12}	f_{13}	f_{14}	f_{17}	f_{18}	Rank
w_i	0.0279	0.0160	0.0216	0.0071	0.3169	0.3383	0.0759	0.0267	0.0628	0.0003	0.0641	0.0424	
2013	5947	5520	10463	3022	18047	190	626	9	148	3819	8452	431	**6**
2014	5878	5464	10826	2988	17078	180	626	9	139	3819	8486	432	**5**
2015	5919	5731	11887	3249	16622	153	605	10	136	3766	8486	432	**3**
2016	5103	4870	11896	3087	13641	191	687	10	120	3766	7277	411	**4**
2017	4997	5081	12352	3288	10229	129	585	10	116	3764	6781	342	**2**
2018	5424	5390	12297	3187	10207	89	462	11	110	3752	6589	371	**1**

transport. The total number of used indicators is 5 and 18 sub-indicators, ie individually for passenger and freight 5 indicators and 12 sub-indicators, based on which the input matrices were formed in the observed period from 2013 to 2018. The importance of each indicator calculated by the Entropy method, while the TOPSIS method was used to evaluate operation performance, ie to rank the results on an annual basis.

In both passenger and freight rail transport, the weighting coefficients show that the Employees in rail transport (f_9) and the Generating power of rail transport - Internal-combustion engines (f_{10}) are the most important while the Effective length of tracks (f_{14}) is the least important indicator (sub-indicator).

Using the TOPSIS method the adopted indicators, for the passenger rail transport system of the Republic of Serbia, were ranked in the time frame from 2013 to 2018, based on which it can be seen that the best operation performances were in 2016, while in 2018 they recorded the worst scenario. When it comes to freight rail transport, it can be stated that the operation performance since the beginning of the observed period in 2013 has improved and the best operational performance is expressed in 2018.

The framework of future research would be reflected in the use of this approach to assess the performance of other systems using compatible evaluation indicators.

ACKNOWLEDGEMENT

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XIX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS RAILCON '20

EUROPEAN RAILWAYS THROUGH TIME AND "STORMS"

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Abstract *– The crisis caused by the COVID-19 virus pandemic has deeply affected all modes of transport, including railway transport. Although trains continued to transport both passengers and goods even at the height of the pandemic, the anti-COVID-19 measures have significantly restricted travels and thus reduced the volume of freight and especially passenger traffic. Railway international organisations, European and national railway institutions and railway market regulators are taking measures to recover the sector, which should help the railways overcome the crisis and prepare for the challenges that await them once the pandemic is over. Among the many results of the implemented actions, a special contribution has been made by the Statement of the Independent Regulators' Group – IRG-Rail adopted at its Plenary Assembly in May 2020, as a support of railway market regulators to the recovery from the COVID-19 crisis.*

Keywords – COVID-19 crisis, railway market, railway transport, railways, pandemic.

1. INTRODUCTION

The coronavirus outbreak has certainly caused serious consequences for the railway sector but railway industry has done its best in order for the passenger and freight railway transport to function. This has been a striking event especially for the passenger traffic - at the peak of the pandemic, in some countries all trains were cancelled (Bulgaria, Romania, Ukraine, etc), cross-border trains were cancelled in Europe and many countries reduced transport for at least 50%. Railway international organizations, European and national railway institutions and railway market regulators are taking measures to recover the sector and help the railways to overcome the crisis and prepare for the challenges that await them once the pandemic is over.

2. UIC - INTERNATIONAL UNION OF RAILWAYS

In order to help its 204 members in 95 countries to fight the COVID-19 crisis, the UIC - International Union of Railways has set up the UIC Covid-19 Task Force [1]. This group brought together 60 UIC members, 12 international organizations, as well as railway experts and other relevant railway stakeholders. For the UIC, the priority was to use its worldwide networks to give the members and other railway stakeholders the possibility to exchange regularly information about the status of transport and preventive measures and procedures. The Task Force held its first meeting by videoconference on 5 March 2020. Since then, many railway companies and partners from all over the world have provided the Task Force with important information which has allowed the publication of documents with concrete measures to help railway stakeholders address this situation.

In March 2020, the UIC published a guidance document - Guidance for Railway Stakeholders - summarizing potential measures to help UIC members and partners find ways to respond to the COvid-19 crisis that are adapted to the railway sector and to collect and share best practices on actions already in place [2]. This document recommends the companies to take preparedness measures, such as creating a company task force, provides guidance for preventive cleaning measures and creating a business continuity plan. It also contains recommendations on how to respond to the crisis and guidance on communication – what and how to communicate and examples of communication material. The main objective was to make trains safe and secure and keep the vital services working.

From late April, restoring customers' confidence became a major issue with the release of a new guidance document –Potential measures to restore confidence in rail travel following the Covid-19 [3]. It focuses on measures to reduce the risk of spreading infection (temperature checks, questionnaires to

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passengers on their health condition, wearing masks, social distancing, etc) and calls for these measures to be shared widely. This document also proposes communication initiatives to reassure the public as well as future research, for example on the impact of wearing masks or social distancing or in other areas related to the pandemic.

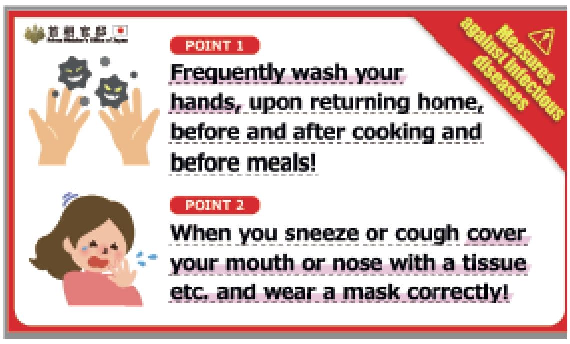

Fig.1. Example of communication material from Japan [2]

Fig. 2. Example of communication material from Austria [2]

Fig. 3. Temperature check (China)

At the end of May, the Task Force published a detailed analysis of the railway response to Covid-19, which revealed the resilience of the railway sector and its capacity to help fight the epidemic and assist the society in general [4].

According to this analysis, most of the UIC members maintained at least the minimum passenger service during lockdowns, while some of them provided up to 90% of their regular service, with the exception of some countries which completely shut down their passenger service as mentioned above.

Fig. 4. Example of social distancing measure – seat stickers (Belgium) [3]

Rail freight has proven to be much more resilient and continued to provide essential goods such as food, coal and medical material during the lockdowns. However, the overall freight traffic was reduced although there were no restrictions imposed on freight by the government.

The rail sector has also supported other sectors. One of the best examples is the SNCF in France, which used their double decked high-speed trains to transport Covid-19 positive patients from the East of the country, where hospitals were full, to the West of the country where hospitals still had enough room.

Fig. 5. Photo taken inside the SNCF medical train (France) [4]

Today the work of the Task Force focuses on helping the railway companies recover and on the economic, managerial and operational impact of the crisis.

3. EU AGENCY FOR RAILWAYS – ERA AND EC

The European Union Agency for Railways – ERA was founded in 2004 and since 16 June 2019 it has become the European Authority for Railways according to the 4th Railway Package – issuing of vehicle authorisations, single safety certificates and ERTMS trackside approvals. Within the European Commission railway relief package, the deadline for transposition of the technical part of the 4th railway package for the EU member states has been postponed to 31 October 2020 by the new EU Directive on the extension of the transposition periods which entered into force on 28 May 2020 [5].

This relief package also includes the Omnibus Regulation extending the validity of safety certificates of railway undertakings and train drivers licences for a period of six months [6].

On 3 April 2020 ERA has issued the "Clarification note on Temporary measures adopted by the European Agency for Railways for delivering authorisations in the framework of the restrictions related to the COVID-19 pandemic", as Notified Bodies (NoBos) may be temporarily prevented from efficiently carrying the planned evaluation activities.

Regarding single safety certificates, ERA has drafted a clarification note covering constraints on the safety certification body side (including an inability to carry out visits, inspections or audits), but also the limited capacity of an applicant to develop, internally agree and submit the relevant evidence and limited possibility for National Safety Authorities (NSA) to perform supervision activities as normal either because of lack of access to a specific railway undertaking or because of resourcing or other problems within the NSA.

The European Union Agency for Railways has supported the NB-Rail Recommendation for use for the remote performance of NoBo activities originally intended to be performed on-site [7]. In order to support business continuity for NoBos, their clients and end-users, on-site activities may be postponed, partially or completely substituted or complemented by equivalent, alternative remote activities.

As a reaction to the COVID-19 pandemic, the European Union Agency for Railways has also set up a dedicated ERA COVID-19 information exchange platform in order to facilitate communication between national authorities and the rail sector [8]. This platform consists of IT tools and communication within the networks of railway representative bodies (NRB) and National Safety Authorities (NSA).

The European Union Agency for Railways has cooperated with the European Commission and the European Centre for Disease Prevention and Control (ECDC) to develop operational guidelines with the COVID-railway protocol [9]. This protocol provides regular information and updates through dedicated information bulletins and gives advice for safeguarding the health and safety of passengers, transport workers and staff or the re-establish trust in rail services.

4. IRG-RAIL

The IRG-Rail is the "Independent Regulator's Group-Rail", a network of independent rail Regulatory Bodies. The Group acts as a platform for cooperation, information exchange and sharing of best practice between national railway regulators. The overall objective of IRG-Rail is to facilitate and promote the creation of a single, competitive, efficient and sustainable railway market in Europe and a consistent application of the European regulatory framework.

IRG-Rail adopted, at its Plenary Assembly in May 2020, the Statement of the Independent Regulators' Group, as a support of railway market regulators to the recovery from the COVID-19 crisis [10].

In the situation where public authorities and economic actors are under pressure and make decisions in an uncertain and difficult environment, IRG-Rail has decided to highlight some important issues that have to be considered regarding the recovery from the crisis. The virus has caused a global decline in transport and the Single European Railway Market is also likely to be affected. It is important that rail regulatory bodies take a flexible approach to regulations in this situation without negative effects on the competition. In this context, IRG-Rail highlights the importance of regulatory cooperation across borders and consistency of administrative processes. This also means that unilateral restrictions to rail markets are to be avoided or should be only temporary.

The recovery of the rail sector will need an improved coordination and cooperation between rail regulatory bodies, but also a strong cooperation of all involved stakeholders.

IRG-Rail has supported the initiative of the EC to adopt a package of relief measures to facilitate transports flows. However, in the context of the open market, those measures should really be considered as an exceptional regime and all the restrictions should be as limited as possible, taking into account the necessity to protect the public health.

IRG-Rail highlights that this emergency situation and the measures taken to fight the crisis should not negatively affect the railway markets or encourage the return of monopolistic system. Therefore, public aid, if necessary, should be available to all railways and not only to the incumbents.

In order to safeguard fair competition and maintain the principles of non-discrimination in rail markets, rail regulators will continue to monitor the competitive situation and offer their support and expertise to rail stakeholders.

Since the crisis and state aid measures are likely to negatively affect competition between the different modes of transport, the IRG-Rail statement also support maintaining efficient levels of rail investment in order to allow further development of sustainable railway networks.

5. CONCLUSION

Due to the outbreak of the COVID-19 pandemic, railways across the globe have been faced with problems of an unprecedented nature and scale.

The actions taken by the rail international organisations, institutions and other rail stakeholders to face the pandemic and recover from the COVID-19 crisis have proven that networks, cooperation, exchange of relevant information and mutual support become all the more valuable during difficult situation.

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FOURTH RAILWAY PACKAGE – NEW CONCEPTS IN THE FIELD OF SAFETY AND INTEROPERABILITY AND THEIR TRANSPOSITION INTO THE LEGAL FRAMEWORK OF THE REPUBLIC OF SERBIA

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***Abstract** – In 2016, the Fourth Railway Package in the EU brings the new Safety Directive (2016/798) and Interoperability Directive (2016/798). They introduce several important new concepts comparing to the previous directive, such as: new competences of ERA which used to be the competences of National Safety Authorities (issuing of authorisations for placing in service, issuing of safety certificates), preauthorisation of the control-command and signalisation subsystem – track side, extension in the field of ECM certification, definition of the "area of use" of railway vehicles as a precondition for issuing of authorisations for placing in service, etc. The biggest problem of transposition of the 4th package into the legislation of the RS are the new competences of ERA, especially those related to the issuing of authorisations for placing in service and safety certificates because ERA is not authorised to accept applications coming from non-EU countries. It is also necessary to solve the problem of access to the register of approved types of vehicles and establishment of the infrastructure register, to extend the scope of application of TSIs to the entire railway network of the RS and all newly constructed vehicles, and procedures to meet the requirements from TSIs shall be prescribed by railway undertakings and infrastructure manager through their safety management systems. At the same time, it is necessary to „clean-up" national rules, i.e. to reduce them to a minimum. Consequently, drafting regulations that will transpose the provisions of EU regulations from the 4th Railway Package into the national legislation, taking into account that we are not an EU memeber state, represents a huge challenge for the Ministry of Construction, Transport and Infrastructure and Directorate for Railways. This paper will elaborate on the new concepts brought by the 4th package and offer the possible solutions for their transposition into the national legislation of the RS.*

Keywords – 4th Railway Package, new concepts, transposition, challenges

1. INTRODUCTION

The Fourth Railway Package is one of the main segments of the European Union's policy to support of the development of the railway sector. The aim of the legal norms from this package is to remove the remaining obstacles in the establishment of the Single European Railway Area. They are divided into two segments: market and technical which is related to the legal norms in the field of safety, interoperability and future competences of the European Union Agency for Railways (ERA).

Within the technical part, new interopearbility and safety directives were adopted, which entered into force in May 2016 and repealed the old directives: Directive 2016/797 on interopearbility of the railway system within the European Union and Directive 2016/798 on railway safety. Regulation 2016/796 on the European Union Agency for Railways (ER) was also adopted, which gave ERA a new name and defined its new competences.

2. NEW CONCEPT OF THE DIRECTIVE ON INTEROPERABILITY OF THE RAILWAY SYSTEM 2016/797

The most important innovations in the new interoperability directive, which are elements of a new concept in this field, relate to:

1. contents of technical specifications of interoperability (hereinafter referred to as: TSI);

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2. issuing of authorisations for placing in service, i.e. authorisations for placing on the market;
3. introduction of a European Vehicle Register (EVR).

2.1. Contents of TSI

A new chapter in the TSI is a list of parameters of vehicles and fixed subsystems which must be checked by the railway undertaking and the procedures to be followed to verify these parameters after the authorisation for placing in service and before the first use of the vehicle in order to ensure the conformity between the vehicles and train paths on which they will operate.

Even before, it has already been the obligation of the railway undertaking to assemble the train so that the train and all the vehicles in it are consistent with the infrastructure, and now, for the first time, it is prescribed in detail what needs to be checked for that purpose.

As our laws cannot prescribe the content of TSIs, this novelty will not be transposed, but the application of the TSIs will oblige the railway undertaking to check the defined parameters.

2.2. Authorisations for placing in service of railway vehicles

Authorisations for placing in service of railway vehicles intended for use in international traffic are issued by the EU Agency for Railways (hereinafter referred to as: the Agency) and authorisations for placing in service in internal traffic are issued either by the Agency or by the national safety authority, at the choice of the applicant.

There are no longer any provisions relating to the issuance of the first authorization for placing in service for TSI compliant vehicles, the issuance of an complementary authorisation for such vehicles, the issuance of the first authorisation for non-TSI compliant vehicles and the issuance of an additional authorisation for such vehicles.

Instead, the so-called “area of use of a vehicle“ has been introduced. It means a part of network or the whole network of one or more states. The applicant applying for an authorisation for placing in service, in addition to the previously known documentation, shall enclose documented evidence that the concerned vehicle is technically compliant with the intended area of use. The compliance is determined according to the relevant TSIs and, if necessary, national rules, registers of infrastructure and common safety method for risk assessment. If necessary, additional tests and test runs may be requested.

The authorization specifies the area of use, and if the vehicle keeper wishes to extend it, he submits to the competent authority (the Agency or national safety authority) a proof that the vehicle is technically compliant with the new part / parts of the network and the competent authority updates the authorisation in the area of use.

The mentioned method of issuing of authorisations for placing in service cannot be applied in the Republic of Serbia. The Agency is not authorized to issue authorisations to entities from third countries. The scope of application of TSIs in the Republic of Serbia is limited.

An authorisation for a vehicle intended for international traffic issued by the Directorate for Railways, in which the networks of other countries would be specified in the area of use, would not be recognized, because only the Agency has such an authorization.

This problem can be solved by keeping the existing principle of issuing the first and complementary authorization in the law, which is in line with the Appendix of COTIF ATMF where the same principle is still applied. The same principle was also prescribed by the previous Interoperability Directive 2008/57. Authorisations issued in this way will be recognized in the EU because according to the agreement on the accession of the EU to OTIF, EU member states apply COTIF in relation to third countries.

Maintaining this principle will enable railway undertakings to continue to procure used and previously approved vehicles, which are not compliant with TSIs, from abroad and to use them in the Republic of Serbia after obtaining a complementary authorisation.

2.3. European Vehicle Register (EVR)

The current principle of registration of railway vehicles is based on national vehicle registers (NVR). Each state kept its own vehicle register and this database was linked to a virtual vehicle register (VVR) in the Agency which functioned as a search engine. The inquiry about a vehicle went to the VVR and from there, according to the country code number (3rd and 4th digits in the 12-digit vehicle number), to the national register of a certain state. This method of vehicle registration was defined by COTIF and by Interoperability Directive 2008/57 and the Directorate for Railways keeps the NVR according to the OTIF regulation.

As of June 2021, NVR and VVR will stop to operate in the EU and the support for the software package used to operate the NVR will not be available any more. From that date, the European Vehicle Register will start operating (EVR).

The EVR represents a centralized database of all vehicles, i.e. data from national registers will be transferred to the EVR which will be kept by the Agency. This register is mandatory for all the EU member states.

The adoption of the OTIF document Vehicle Register Specification, which is based on the vehicle register specifications defined in the European Commission Decision 2018/1614, is expected by the end of September 2020.

The following options are available to the non-EU countries:

1. to continue to keep a NVR based on their own software and to inform about how this register can be accessed by the interested parties, both from the Republic of Serbia and from other countries;

2. to use the EVR for the registration of their vehicles or

3. to establish and keep a common register with other interested parties.

For the Republic of Serbia, the simplest solution from the organizational and technical aspect is to use the EVR. The financial conditions for the use of the EVR would be regulated by bilateral agreements between the Agency and the interested countries. In that case, it is likely that the vehicle registration fee will be significantly higher than today (100.00 dinars per vehicle, once for the entire life cycle of the vehicle until it is withdrawn from service).

In any case, before amending the Law on Interoperability of the Railway System, one should have a clear position on the issue of keeping the vehicle register and amend the provisions on the vehicle register accordingly.

3. NEW CONCEPT OF THE SAFETY DIRECTIVE 2016/798

The most important innovations in this directive relate to:
1. two new common safety methods (hereinafter referred to as: CSM);
2. new concept of issuing of a single safety certificate;
3. extension of certification of entities in charge of maintenance (hereinafter referred to as: ECM).

3.1. Common safety methods

Safety Directive 2016/798 provides for the following CSMs:
1. CSM for risk evaluation and assessment;
2. CSM for assessing conformity with requirements in safety certificates and safety authorizations;
3. CSM for supervision to be applied by national safety authorities and CSM for monitoring to be applied by railway undertakings, infrastructure managers and ECMs;
4. CSM for assessing the safety level and the safety performance of railway operators at national and Union level and
5. CSM for assessing the achievement of safety targets at national and Union level.

CSMs from points 1-3 are already known but CSMs from points 4 and 5 are new.

The Regulation 402/2013 on CSM for risk evaluation and assessment amended by the Regulation 2015/1136 is still in force. The Republic of Serbia applies the OTIF's CSM for risk evaluation and assessment which is equivalent to the mentioned EU regulations.

A new Regulation 2018/762 on CSM related to the requirement to establish a safety management system has been adopted. The previous Regulations 1158/2010 and 1169/2010 on CSM for assessing conformity with requirements in safety certificates and safety authorizations will be in force until 16.06.2025 and they apply on certificates issued according to the Safety Directive 2004/49. The transposition of Regulation 2018/762 into a bylaw should not be considered before 2024.

A new Regulation 2018/761 has been adopted for supervision by national safety authorities after the issuance of safety certificates or safety authorisations, which has repealed the Regulation 1077/2012. The Regulation 1077/2012 was transposed in 2015 into the Rulebook on CSM for assessing safety performance after the issuance of a safety certificate or safety authorisation and, therefore, a new Rulebook base on the Regulation 2018/761 should be adopted. It is not necessary to change the existing legal basis for this.

The Regulation 1078/2012 on CSM for supervision to be applied by railway undertakings, infrastructure managers and ECMs is still in force. This regulation was transposed in 2015 into the Rulebook on CSM for monitoring of the efficiency of safety management during exploitation and maintenance of the railway system so nothing needs to be changed in that sense.

CSM for assessing the safety level and the safety performance of railway operators at national and Union level has not been adopted yet, so it is not known what will be written in it and what will be transposed into a bylaw.

CSM for assessing the achievement of safety targets at national and Union level has also not yet been adopted. The term safety targets is known from the previous Safety Directive 2004/49. Those targets are defined by the European Commission for the member states so it is not purposeful to transpose this CSM in a bylaw.

3.2. Single safety certificate

There is no part A and part B certificate any more but a single safety certificate.

The application for issuance of the certificate shall be accompanied by documentation containing documented evidence:

1. that the railway undertaking has established its safety management system which meets the requirements defined by TSIs, CSMs and common safety targets and by other relevant legislation in order to manage the risks and ensure safe operation of transport services on the network and

2. that the railway undertaking, if applicable, meets the requirements defined by the relevant national rules.

The Agency issues a safety certificate to railway undertakings operating in international traffic and before that it assesses the fulfilment of conditions from point 1. and submits the documentation form point 2. to national safety authorities for assessment. The certificate states the area of operation of the railway undertaking.

For the issuance of a safety certificate in internal traffic, the railway undertaking can apply to the Agency or to a national safety authority.

The Agency cannot issue safety certificates to railway undertakings from the Republic of Serbia.

Issuance of a single safety certificate in our country is possible for internal traffic, however, we should take into account the Treaty establishing the Transport Community (TC) which provides for the opening of the railway markets of the member states.

The degree of harmonization of the laws of these countries with EU regulations is very different. The Republic of Serbia has gone the furthest in that, not only in terms of harmonization but also in implementation.

It is necessary to agree on the type of safety certificate at the level of the TC, which will be mutually recognized. At the level of the TC, there is no “supranational” body such as the EU Agency that could issue safety certificates valid in two or more countries.

It is not possible for the competent authority of one member state of the TC to issue a safety certificate stating that it is also valid in another state.

The solution is to keep the old concept in the form of a part A certificate that would be recognized by all member states of the TC and one or more parts B certificate that would be issued by the competent authorities of each state.

3.3. ECM certification

According to the previous Safety Directive 2004/49, only ECMs for freight wagons had to be certified.

Article 14, paragraph 4 of the Safety Directive 2016/798 lays down that in case of freight wagons, and, after the adoption of the implementing act from paragraph 8, in case of other vehicles, all ECMs must be certified and obtain an ECM certificate.

The implementing act has been adopted in form of the Regulation 2019/779 on the system of certification of entities in charge of maintenance of vehicles.

Amendments to the Law on Railway Safety should prescribe the obligation for all ECMs to be certified and as far as the manner of their certification is concerned, reference should be made to the relevant OTIF regulation, as is the case in the applicable law.

The OTIF document Certification of Entities in Charge of maintenance base on the Regulation 2019/779 is expected to be adopted by the end of September 2020.

4. CONCLUSION

The Interoperability Directive 2016/797 and Safety Directive 2016/798 from the 4th Railway Package bring several important innovation in relation to the relevant directives from the 3rd Railway Package and new concepts that assign new roles to the Agency and to some extent to national safety authorities.

It is generally not possible to transpose these innovations into the regulations of the Republic of Serbia (content of TSI, authorisation for placing in service with the definition of the area of use, CSM for assessing the achievement of safety targets, single , safety certificate for international traffic), and some of them are not required to be fully transposed for the moment thanks to the application of the equivalent OTIF regulations (vehicle register, CSM for risk evaluation and assessment, ECM certification).

The planned amendments to the Law on Interoperability of the Railway System and Law on Railway Safety will generally not make it possible to harmonize with the 4th Railway Package for the reasons mentioned in this paper. Therefore, the best solution at the moment is to pay the greatest attention to eliminating the shortcomings and inaccuracies of these laws detected during their application.

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XIX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS RAILCON '20

THE ROLE OF TREATY ESTABLISHING TRANSPORT COMMUNITY IN DEVELOPMENT OF RAIL TRANSPORT MARKET IN SERBIA

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Abstract *– Opening up national freight and passenger rail markets to competition in cross-border and cabotage operations was a long and demanding process, conducted in the European Union with the aim to provide for more efficient and customer-responsive rail industry and also, more competitive vis-à-vis other transport modes. Establishing competition in rail market in Serbia by providing access to railway infrastructure to all interested railway undertakings on non-discriminatory basis was the necessary step in the process of restructuring in railway sector, also in order to achieve more competitive and efficient rail transport. Rail market in Serbia is opened to competition at the national level, however, its integration in European rail market is needed for increasing the quality of rail services and railway's modal market share. Treaty establishing Transport Community provides legal basis for the progressive integration of Serbian transport market into the European Union transport market.*

Keywords – rail market, Transport Community, Treaty, connection, rail services.

1. INTRODUCTION

Rail transport is recognised as one of the most environmentally friendly transport modes, as well as the safest form of land transport in Europe today.

After a long period of decline of the railway transport mode in Europe, over the last decades massive effort in European Union (EU) has been done for its revitalization and improvement of rail transport services, as well as the increase of its modal transport market share.

European Commission Communication COM (2019) 640 final published on 11 December 2019 set out a European Green Deal for the EU and its citizens, with the objective of achieving a climate-neutral European Union by 2050. In the "Green Deal" Commission states that, as a matter of priority, a substantial part of the 75% of inland freight carried today by road should shift onto rail and inland waterways.

In order to promote rail transport mode, considering its significant role in accelerating the reduction in transport emissions, as one of the most environmentally friendly and energy-efficient transport modes, in March 2020, the Commission presented its proposal for a Decision of the European Parliament and of the Council on a European Year of Rail (2021). The objective of the European Year of Rail should be to encourage and support the efforts of the EU, the Member States, regional and local authorities and other organisations to increase the share of passengers and freight moving by rail. This proposal shall also contribute to promoting rail as an important element of the relations between the Union and neighbouring countries, in particular in the Western Balkans, building on the interest and needs in partner countries and on the Union's expertise in rail transport.

In order to fulfill these expectations and to seize the presented opportunity to develop, rail transport must be improved. This will require actions on the integration of the rail netwok and rail market opening at the European level, including non-EU memeber states, particulary in Western Balkans, actions for development and maintenance of the rail TEN-T network infrastructure, actions on improving rail border-crossing operations, on digitalisation etc.

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2. MARKET OPENING IN SERBIA

Harmonisation of the Serbian national railway legislation with the relevant EU acquis began in 2005 with the Law on Railways that provided for new entrants in railway transport market. Further harmonisation with the EU rail legislation was done by the Law on Railways adopted in 2013, amended in 2015 and 2017, and with the Law on Railways ("Official Gazette RS, No. 41/18), now in force.

Although the rail market in Serbia has been legally opened for competition for railway undertakings established in Serbia since 2005, it has been actually opened only after the integrated railway company, "Serbian Railways" JSC, was unbundled. In July 2015, the Government of the Republic of Serbia adopted founding acts for three new companies, "Srbija Voz" JSC (Serbia Train), "Infrastruktura železnica Srbije" JSC (Infrastructure of Serbian Railways) and "Srbija Kargo" JSC (Serbia Cargo). Directive 2012/34/EU (amended by Directive (EU) 2016/2370 and Commission Delegated Decision (EU) 2017/2075) provides for possibility for holding organization under certain conditions, however, in Serbia complete separation of activities related to the infrastructure, passenger services and freight services was done.

The first Network Statement was published by Infrastructure Manager in 2016, and the same year the first new entrant gained access to railway infrastructure.

Regional cooperation and cooperation with the EU in the field of railway transport was organised by the South East European Transport Observatory (SEETO) in the framework of the Memorandum of Understanding on the development of the South East Core Regional Transport Network signed in Luxembourg on June 11, 2004 signed by Albania, Bosnia and Herzegovina, Croatia, the former Yugoslav Republic of Macedonia, Montenegro, Serbia, the United Nations Mission in Kosovo and the European Commission and its Addendum for a South East European Railway Transport Area, signed in Tirana on December 2007.

3. TREATY ESTABLISHING TRANSPORT COMMUNITY

In Explanatory Memorandum for its Proposal for a Council Decision on the conclusion, on behalf of the European Union, of the Treaty establishing the Transport Community (COM(2018) 532 final) European Commission pointed out that a well-functioning transport system connecting the Union and the neighbouring countries is essential for sustainable economic growth and the wellbeing of all citizens. As the Memorandum of Understanding has shown limits and following an assessment made by the Commission in 2008, a more comprehensive cooperation approach – involving other transport policies and transport related areas – was suggested. In this context, based on the positive experience with the implementation of the Energy Community Treaty, the Commission proposed to take inspiration from this example for the purposes of the transport sector and negotiate an agreement providing that the legislation, standards and technical specifications applied by the Western Balkans partners be made compatible with those of the Union.

The Treaty establishing the Transport Community (hereinafter: Treaty) was signed by the European Union and six South East European partners, 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 and has entered into force on 1 May 2019 in accordance with its Article 41(2). All parties have ratified or approved it.

The aim of the Treaty is the creation of a Transport Community in the field of road, rail, inland waterway and maritime transport as well as the development of the transport network between the European Union and the South East European Parties. The Transport Community shall be based on the progressive integration of transport markets of the South East European Parties into the European Union transport market on the basis of the relevant acquis, including in the areas of technical standards, interoperability, safety, security, traffic management, social policy, public procurement and environment, for all modes of transport excluding air transport. For this purpose, this Treaty sets out the rules applicable between the Contracting Parties under the conditions set out hereinafter. These rules include the provisions laid down by the acts specified in Annex I.

Annex I.2 specifies rules applicable to rail transport. The European Union acts are divided in following regulatory areas:

- Market access
- Train driver licensing
- Interoperability
- European Union Agency for Railways
- Railway safety
- Inland transport of dangerous goods
- Transportable pressure equipment
- Social field - working time / hours
- Passenger rights.

Article 11 refers to railways and provides that within the scope and conditions of the Treaty and within the scope and the conditions set out in the

* *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.*

relevant acts specified in Annex I, railway undertakings licensed in an EU Member State, or by a South East European Party shall have the right of access to the infrastructure in all EU Member States and South East European Parties for the purpose of operating international rail passenger or freight services.

Paragraph 2 of the same article provides that within the scope and conditions of the Treaty and within the scope and the conditions set out in the relevant acts specified in Annex I, there shall be no restrictions on the validity of licenses of railway undertakings, their safety certificates, the certification documents of train drivers and rail vehicle authorisations granted by the EU or a Member State's competent authority or a South East European Party.

3.1 Transitional arrangements

Transitional arrangements applying between the European Union, on the one hand, and the South East European Party concerned, on the other hand are regulated by article 40 of the Main Treaty and Protocols I to VI of the Treaty.

The gradual transition of each South East European Party to the full application of the Transport Community shall be subject to assessments. The assessments shall be carried out by the European Commission in cooperation with the South East European Party concerned. The European Commission may launch an assessment upon its own initiative or at the initiative of the South East European Party concerned.

If the European Union determines that the conditions are fulfilled, it shall inform the Regional Steering Committee, which is responsible for the administration of the Treaty and its proper implementation, and decide thereafter that the South East European Party concerned qualifies for passing to the next stage of the Transport Community.

If the European Union determines that the conditions are not fulfilled, the European Commission shall so report to the Regional Steering Committee. The European Union shall recommend to the South East European Party concerned specific improvements.

Transitional arrangements between the European Union, of the one part, and the Republic of Serbia, of the other part, are regulated by Protocol VI of the Treaty.

3.2 Transitional periods

The Treaty provides for two transitional periods before its full implementation:

- Rail market opening for competition on national level;
- Rail market opening for competition on regional level.

Provisions related to transitional periods for railways are prescribed in Section I. of the Protocol VI

- Conditions relating to transition for rail transport.

The first transitional period shall extend from the entry into force of the Treaty until following conditions have been fulfilled by Serbia:

- all railway legislation as provided for in Annex I is implemented;
- sufficient progress in implementing the rules on State aid and competition in accordanse with the Treaty is made.

The second transitional period shall extend from the end of the first transitional period until the Treaty is applied in Serbia, including all railway legislation and the rules on State aid and competition in accordanse with the Treaty.

Fulfillment of these conditions related to first and second transitional period shall be verified by an assessment carried out by the European Commission in accordance with the procedure referred to in Article 40 of the Main Treaty.

Serbia may ask the European Commission at the end of the first transitional period to assess progress in accordance with Article 40 of the Main Treaty with a view to pass directly to market integration according to Article 11 of the Main Treaty.

During the first transitional period railway undertakings licensed in Serbia shall be granted access to railway infrastructure in Serbia.

During the second transitional period railway undertakings licensed in Serbia shall be permitted to exercise the traffic rights provided for in the railway legislation referred to in Annex I on railway infrastructure of any other South East European Party.

3.3 The Permanent Secreteriat

The Permanent Secretariat of the Transport Community is established by the Treaty, in order to:

- provide administrative support to the the other institutions of the Transport Community, Ministerial Council, the Regional Steering Committee, the technical committees and the Social Forum;
- act as a Transport Observatory to monitor the performance of the indicative TEN-T extension of the comprehensive and core networks to the Western Balkans;
- support the implementation of the Western Balkans Six (WB6) Connectivity Agenda aiming to improve links within the Western Balkans as well as between the region and the European Union.

The seat of the Permanent Secretariat is in Belgrade, Serbia.

First Technical Committee on Railways was held in Brussels on May 23, 2019 and since then this Committee has been very active, especially during COVID 19 crisis.

The Transport Community Secretariat is also active in connecting railway sector stakeholders and providing for the proper coordination of the activities carried out by other institutions and organisations as European Commission, European Union Agency for Railways, IFIs, Shift2Rail etc, with the aim to ensure synergies and complementarity in using the Technical Assistance devoted to the rail sector.

4. RAIL MARKET IN SERBIA

Rail market in Serbia is in the first transitional period, as it has been opened for competition on national level since 2016.

In 2020 there are 11 railway undertakings operating on the railway network:

- 1 for passenger transport services (incumbent);
- 7 for freight transport services (1 incumbent, 6 new entrants);
- 3 RUs for its own purposes.

In 2019 there were 10 railway undertakings operating on the railway network:

- 1 for passenger transport services (incumbent);
- 6 for freight transport services (1 incumbent, 5 new entrants);
- 3 RUs for its own purposes.

Railway undertakings market share as a percentage of tonnes-km in 2019, using data from the Directorate for Railways Report on rail services market regulation in 2019, is shown in Fig. 1.

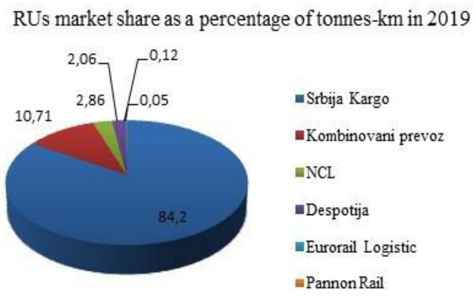

Fig.1. RUs market share in 2019

Althow the number of new entrants in railway freight market was growing witnin the period 2016-2020, the pie is not expanding, since the market share of rail vis-à-vis other transport modes is declining in the same period. It is shown in the Fig. 2, using data provided by statements on total transport of passengers and goods for 2016-2019 issued by Statistical Office of the Republic of Serbia.

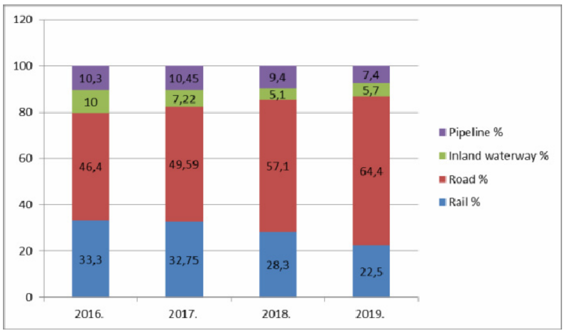

Fig.2. Modal share in freight for 2016-2019

It should be noted that decline in rail modal share in 2019 is related to major works on the railway infrastructure in Serbia in 2019.

These data show that opening rail market for competition is far from enough to make rail competitive vis-à-vis other transport modes, especially road transport. It means that much more has to be done in order to increase the capacity of railways and achieve more competitive, more efficient and customer-responsive rail transport in Serbia.

5. CONCLUSION

Further rail market opening for competition for international rail passenger and freight services, firstly on the regional level and then between Serbia and EU countries shall take place in the framework of the Treaty.

Transitional periods are the opportunity for all stakeholders in railway sector in Serbia to prepare for the full implementation of the Treaty, with assistance of the Permanent Secretariat all the way, providing for the EU expertise in railways and best practices in relevant EU acquis.

Integration of the European rail network is prerequisite for increasing the quality, punctuality, and reliability of rail services in order to meet passenger and industry needs, and thus to provide for modal shift needed to fulfill increased EU's climate ambition stated in the Grean Deal.

More competitive rail transport needs comittment of all stakeholders in railway sector and continued cooperation and coordination of relevant activities related to development of railway transport, which shall be done in the framework of the Treaty.

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WESTERN BALKAN RAILWAY MARKET THROUGH THE SCOPE OF THE REGULATORY BODY – BENCHMARK WITH EUROPE

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Abstract *– With the process of railway restructuring well on the way and, in some European countries, considerable rail market openness level, new challenges arise. Keeping track of the restructuring progress and rail market development is a constant challenge and it also presents a very important issue for the states' governments. This task is mostly served by regulatory bodies, through various market monitoring techniques and assessments of railway market liberalization. For this task to be done right, the communication between the state and the regulatory body needs to be appropriate through clear goals set by the state and an adequate response from the regulatory body, and railway market monitoring indicators are a key feature of this communication. The set of common indicators and various measures are used for completing this task by European regulatory bodies. Where is Western Balkan railway market in relation to current European countries' railway market and goals according to these indicators? In this paper we try to give an answer why certain indicators are important and how they are interpreted by using benchmark to collect data and exploring indicators for market monitoring.*

Keywords – goals, politics, market monitoring, quality data.

1. INTRODUCTION

In today's market of constant and frequent changes, it is crucial for every participant to know, and above all, understand his place in the market. Railway market, although quite less dynamic, certainly makes no exception in this context, yet it possesses a significant distinction which is manifested through tight connection to the government's transport policy despite formal railway market liberalization and vertical separation of monopolistic railway company. Perhaps a bit contrary to logic, what ensued after liberalization was an even greater need by government to have a clear insight in railway market in order to have up to date information about the level of competition, possibilities and barriers for market entrance, market shares of private operators in relation to incumbent etc. These and other market "indicators" are mainly shown and evaluated in annual reports of regulatory bodies.

For the purposes of monitoring and evaluating market conditions and the extent of government goal fulfillment, regulatory bodies are tracking and analyzing a large number of indicators, which are now de facto unified across entire Europe because of the general tendency for railway markets to be comparable and to finally form a single European railway market. Thanks to that fact, it is possible nowadays to obtain sufficiently reliable data from various railway markets across Europe, even for different market segments. However, in order to have a clear picture of any given railway market, it is essential to interpret the data in the right way and in accordance with the circumstances specific to the given market.

In this context, western Balkan (WB) countries make no exception, because their railway markets also possess their own distinctions. Although most of these markets emerged from the break-up of former Yugoslavia, and at least in theory they could possess many common characteristics, that may not be the case in reality.

Many of the indicators were once common, but in current development, they may not prove themselves to be the key ones for each separate market and they even could be pointing to different conclusions, which makes the analysis of these markets quite interesting.

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2. MARKET DEVELOPMENT IN WB

As stated earlier, market development is monitored through certain indicators, and analysis and monitoring quality is essential for guiding the government's railway policy. Current European railway policy is to reduce railway subsidies, which is for most part the reason why performance indicators are much more perceived from "commercial" aspect, in contrast to the past days when they were mostly tracked for the sake of assessing the asset utilization, technological processes harmonization and "pure statistics". Therefore, due to this shift, the indicators are now interpreted much more as measures of "commercial" rather than "engineering" features, by now greater number of present stakeholders than before. A significant number of these indicators now has a new role in serving the regulatory bodies to depict the current market state in their reports to government offices responsible for creating the railway policy.

Before we analyze the indicators which are depicting the current state of WB railway market, it is important to note that markets in Albania and Bosnia and Herzegovina are not yet formed, i. e. the legislation exist and allows it, but it is still to be realized in practice. Having that in mind, further on only the data for Serbia, Croatia, Northern Macedonia and Montenegro shall be analyzed, given that in these countries a vertical separation of monopolistic railway company was done.

Therefore, in order to properly view the market conditions, one should have in mind market's level of development, which is primarily shown through a number of market participants and private operators' market shares. In other words, the indicators have to be interpreted with taking into account the current level of market development in order to obtain a realistic picture of the conditions and to direct railway policy. In practice, this would mean that the indicators cannot be interpreted (or tracked) from the same aspect in the newly formed markets as it would be the case with already formed and stable markets.

Therefore, it is essential for depicting the state of WB railway market to present the data for vertical separation and market liberalization moments which are shown in Tab. 1.

Tab.1. Western Balkan railway market state

Country	Vertical separation	Market liberalization
Serbia (SRB)	August 2015	Yes
Croatia (HR)	November 2012	Yes
N. Macedonia (MK)	April 2007	No
Montenegro (MNE)	March 2009	Yes

From Tab. 1 it can be observed that both vertical separation and market liberalization were performed in Serbia, Croatia and Montenegro, while in N. Macedonia only vertical separation to infrastructure manager and a single passenger/freight operator was done. One of the reason for that is the fact that Croatia is already an EU member state, while Serbia and Montenegro are in formal EU joining process, and therefore there was a significant amount of pressure to perform these actions, with bearing in mind their geographical location. In case of N. Macedonia, a logical approach to gradually open market was chosen, given that there is no significant pressure from EU, and also the current market state is such that this kind of scenario does not yield foreseeable advantages both to the state and market participants.

3. CURRENT WB MARKET STATE

Primary indicator of martket state is the one directly refering to the level of market openness, which would be the total number of railway companies competing in passenger and freight traffic. However, this indicator should not be perceived as necessarily crucial for assesing the market openness level, because of the many barriers which potentially hamper the entrance of new operators. Therefore, for properly assesing market state, openness and competition levels, it is necessary to look at a wide array of circumstances. The current number of active market competitors in WB countries is given in Fig.1

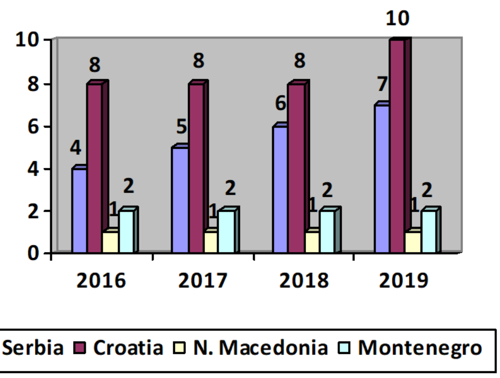

Fig. 1. Number of market competitors [1],[2],[4]

It is characteristic for all countries that only one operator in passenger traffic is present, which implies that market openness level can only be assessed for freight traffic. Serbia and Croatia lead the lot in that sense, because they obviously have opened their markets for entrance of private operators in freight traffic, which can be seen in Fig. 2, which shows private operators' market shares related to the incumbent. Croatia even went a step further by opening its market to foreign operators.

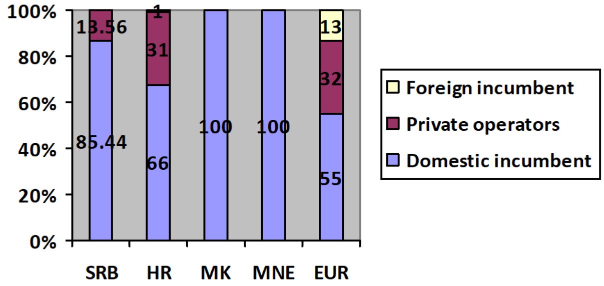

Fig.2. Freight market shares [4]

At European level, it is very important to show the data about market segmentation in the sense which type of transport is more present – passenger or freight. In majority of European countries, passenger traffic is the dominant one, with 82% of market share according to train kilometers on average. In WB countries this is also the case, because it is also higher than the freight traffic share, but with a smaller margin between the two, which can be observed in figure 3. This smaller margin could be due to poor track quality, inadequate reliability and small passenger flows, which also could be the reasons of small number of passengers per train (Fig. 4.).

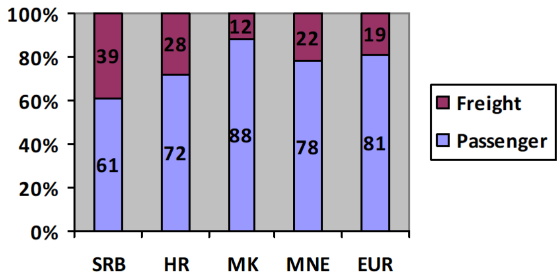

Fig. 3. – Passenger and freight traffic market share [4]

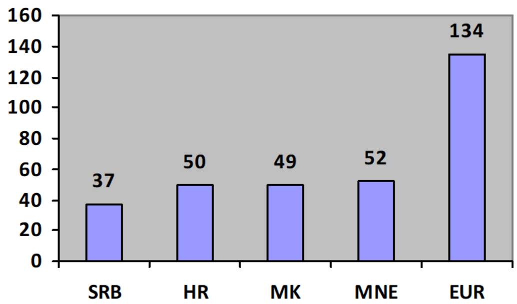

Fig. 4. Average number of passengers per train [4]

When it comes to freight traffic, the situation is quite different. In this market segment, WB countries have some decent numbers. Not only that Serbia and Croatia have significant number of private operators, but the average load of trains is similar to European average. In N. Macedonia and Montenegro, average load is around 1600t and 700t, which is quite above European average (Fig. 5.).

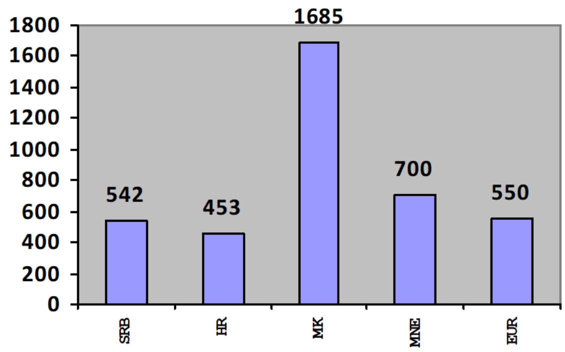

Fig.5. Average train load [4]

What shouldn't be left out is the data showing the level of railway network utilization in the form of total number of train km per network km per day. According to this indicator, WB countries are placed quite low, which is shown in figure 6. However, this indicator is not neccecarily crucial, because it shows the number of trains in traffic per day, but it does not show how full with passengers/load these trains are.

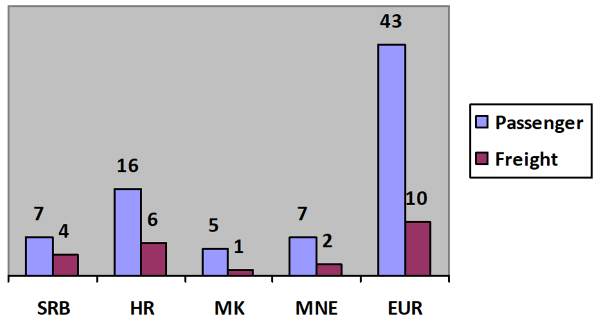

Fig. 6. Network utilization [4]

Another very important indicator at European level is percentage share of public service obligation (PSO). It shows the overall development strategy in passenger traffic, and therefore it is significant for it to find its place in the analysis. With current market openness level, the only conclusion that can be drawn is that PSO is heavily dictated by the government rather than by market conditions, i.e. according to the demand for transport. However, this indicator is one of the most important ones at the European level, and its placement in this paper is due to that fact and also because the conditions on the market could be changed with future development, and it is shown in Fig. 7.

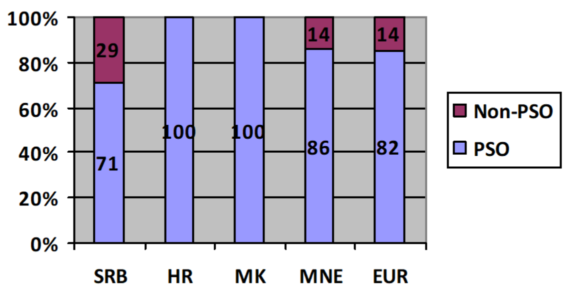

Fig.7. Percentile share of PSO traffic [4]

4. TRACK ACCESS CHARGES AND ENTRY BARRIERS

For assessment of market conditions, fees (track access charges – TAC) will always be number one factor, which by itself can be a topic of detailed and broad analyses. Market TAC is in fact an instrument of market regulation and an "unseen force of regulation", thus its adjustment significantly affects market conditions, and it can often represent a direct consequence of government policy, especially when it comes to transport.

In railway market, TAC also have a central role, and their level and calculation formulas are a current topic since the moment market was formed. What is a bit specific about railway market is that there are many different formulas to calculate the TAC for basically the same service. Most of the infrastructure managers across Europe have their own way in calculating the charges, and thus the formulas for calculating TAC vary significantly. Average WB track access charges both for passenger and freight traffic are shown in Fig. 8. for 750-1100 gross tonne trains in freight and 200 gross tonne trains in passenger traffic in comparison to European average.

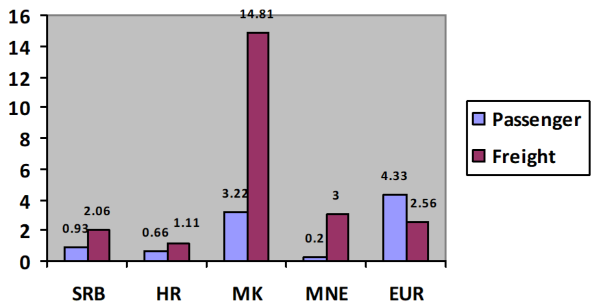

Fig. 8. Average track access charges (TAC) [1], [4]

When it comes to market entry barriers, they also vary across different markets. Which barriers are most influential in hampering new market entrants is a topic for a thorough analysis for each market individually, but in the most regulatory bodies' reports it is stated that high initial cost of rolling stock procurement is the biggest one [3]. However, there are many other barriers dependent on market conditions which could be crucial in hampering potentially new entrants, such as low traffic flows, lack of trained staff, incumbent operator who knows the market very well, etc [3].

Current level of market analysis in WB countries is not on such level to reliably mark the crucial barriers, making one such analysis heavily based on the assumptions. For example, one such assumption would be that high initial cost of rolling stock procurement could be marked as biggest barrier, which may not necessarily be the case.

5. CONCLUSION AND FINAL ANALYSIS

Having in mind that WB railway markets are relatively recently liberalized, and that they are still in the early development phases, any direct comparison to already advanced European railway markets is not realistic. It is more realistic to determine some of the benchmark markets. In this paper, the average European data is given more as a "whereabout" comparison.

General level of market development points to a significant difference between passenger and freight transport markets – especially in accordance to development in Europe. According to the indicators, passenger traffic market is at low level of development, that it practically does not exist, since only one incumbent operator is serving this market segment mostly based on PSO contracts with a small passenger flow. It is a huge difference compared to Europe, where many private operators are serving this market segment.

In freight traffic, the condition is rather different, especially in Serbia and Croatia. In these two countries, market is opened as it should be, with a stable number of private operators in Croatia for years now, and a rising number in Serbia each year. Market shares of these private operators are already significant according to both train and tonne kilometers [1], [2]. According to European criteria, markets in Serbia and Croatia would be identified as "developing markets", making them somewhat comparable to European markets. Although because of goods flow and some other factors it is not realistic to reach European level, markets do behave similarly, because of the existence of noticeable number of private operators which will certainly grow in the coming years.

What could be the cause of such a difference between passenger and freight market, it is a matter of discussion and a detailed analysis. It might be possible that in fact the barriers in passenger traffic are more hampering than the ones in freight traffic, and they avert new entrants right away. The largest of these barriers would be a non-profitable service in passenger market in combination with high cost of rolling stock procurement and a direct PSO contract awarding in a market with an obviously small passenger flow, while in freight traffic goods flow is large enough to attract new market entrants.

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Other Railway aspects

NUMERICAL SIMULATION OF THE WELDING PROCESS, THE INFLUENCE OF CONSTRAINT POINTS LOCATIONS ON THERMAL DEFORMATIONS

Tomasz ZADOROŻNY[1]
Miroslaw SZCZEPANIK[2]

Abstract *– Many potential risks and issues can be discovered during the welding process by numerical simulation. This approach can reduce costs by minimizing deformations and necessary repairs. The article will present the influence of constraint points locations on thermal deformations during the welding process. For the given geometry and type of weld, the thermal deformations have been simulated by means of numerical simulation based on the Finite Element Method. Five different cases of constraint points locations on welded construction have been analyzed. Finally, the results for the discussed cases obtained for different density of finite element mesh will be presented.*

Keywords – Welding, numerical simulation, thermal deformation, rolling stock welded parts, FEM

1. INTRODUCTION

The technique of joining elements by welding is widely used, especially in the railway industry. The course and size of deformations arising during the welding process are difficult to determine on the basis of experience, therefore, with low-volume constructions, obtaining satisfactory results is often impossible. Deformed components require repairs that are time-consuming and can cause material damage, generating significant financial losses. Deformations mainly depends on constraint points and parameters of process (parameters determinate the temperature). Changing the process parameters is heavily limited by the requirements for the quality of the welds, and often varies slightly throughout the process. Therefore, the key role in minimizing thermal deformation is the proper fixation of the component. The use of advanced numerical simulation methods allows for adjustment of the attachment points of individual parts that minimizes the risk of deformation [1],[2]. To maintain the correctness of the solution, the appropriate number of finite elements should be provided, which in the case of large assemblies used in railway industry, is a big difficulty. The process can be reproduced most precisely by using 3D elements, however, it is often hard to obtain due to their excessive number, which makes it very time-consuming. Optimization process strictly depends on the time of solving a single task and is extended with each subsequent iteration, consequently, at the very beginning of defining the optimization method, one should try to reduce the number of elements as much as possible. Therefore, the aim of this work is to present an alternative method using 2D types of elements, which will allow to assess the magnitude and course of deformation in order to minimize them by appropriate selection of constraint points. The article presents the first stage of work aimed at developing a constraint point optimization method for large-size components used in railways. The first tests showed that the 2D elements allow the achievement of sufficient accuracy for this kind of task. One of the commercial finite element method (FEM [3]) HyperWorks programs was used to solve the problem defined above.

2. DESCRIPTION OF THE ANALYZED STRUCTURE

The analyzed welded structure consists of aluminum sheets of different thicknesses, which are weld used fillet weld. The analyzed structure is relatively small, its dimensions are 800x450x250mm. Figure 1 presents its geometry. Table 1 displays the basic material properties.

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Tab. 1. Material properties

Young's modulus [MPa]	$7 \cdot 10^4$
Density [g/cm³]	2,7
Poisson ratio	0,3
Thermal conductivity [W/(m·K)]	215
Thermal expansion coefficient [$10^{-6} \cdot K^{-1}$]	23,1

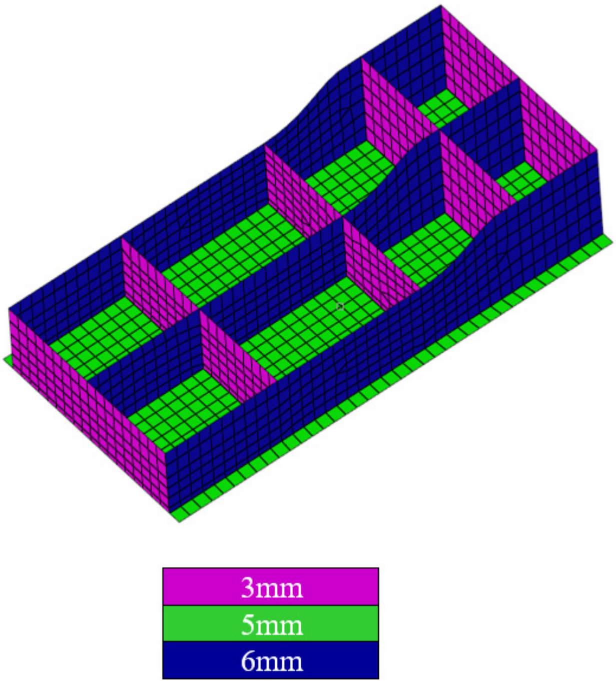
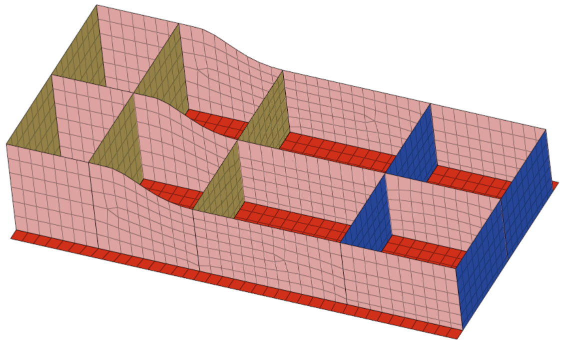
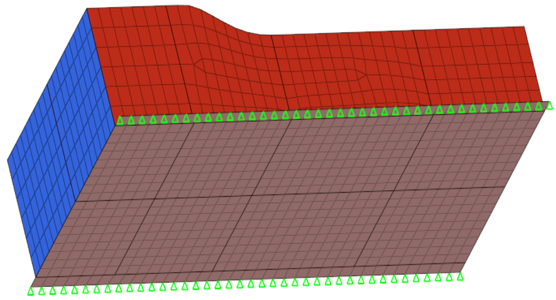
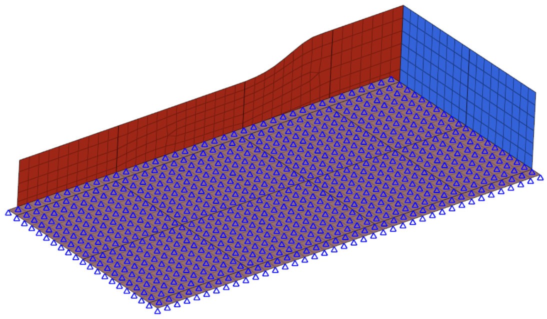
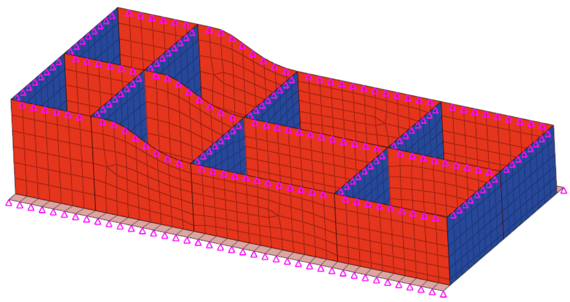


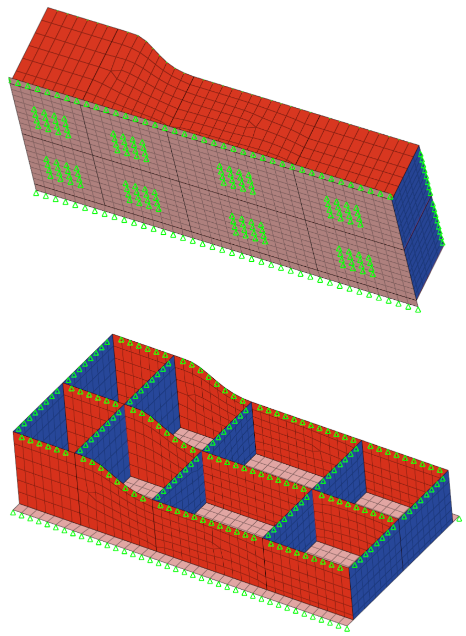
Fig.1. The distribution of sheet thickness in the analyzed structure

3. NUMERICAL MODEL AND BOUNDARY CONDITIONS

The article compares 5 different ways of constraining the welded structural components. In order to check the effect of mesh density on the results, calculations were carried out for a mesh with an average element size of 20x20mm, 10x10mm and 5x5mm. For each case, the mesh was created from shell elements. Table 2 presents details of the constraint method for each case. The welding temperature used for calculations is 1230ºC, which corresponds to the actual value measured during welding tests. The temperature was applied to each plate connection along its entire length (boundary condition of the first type – Dirichlet) [2]. The ambient temperature of 20ºC was adopted in the rest of model.

Tab. 2. Boundary conditions

 W1-Structure wihout any support
 W2-Fixed edge of the bottom plate
 W3- Fixed bottom plate
 W4- Fixed edge of the lower plate and ribs on the upper edge



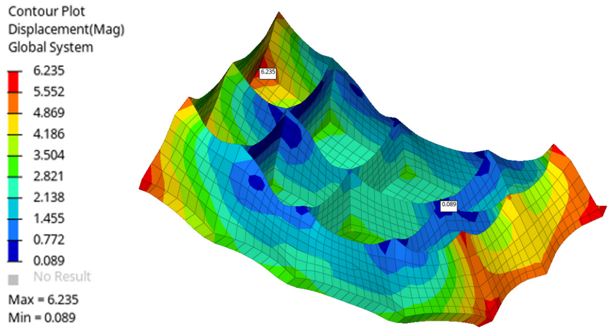
W5 - The bottom plate was fixed at the edge and locally in each of the baffles, in addition, ribs were fixed at the upper edge

4. RESULTS

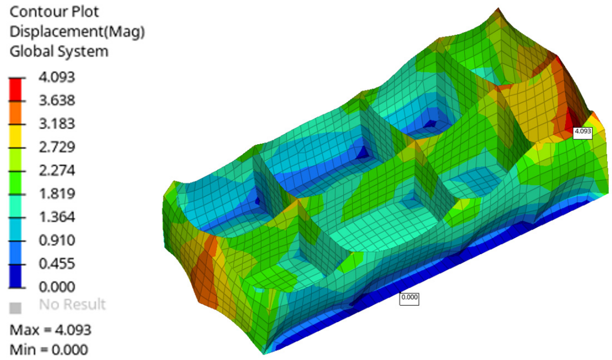
Table 3 shows the displacement distribution on the deformed model for the mesh density of 20x20mm, the deformation scale is 1:20. The results for all analyzed finite element mesh densities are summarized in table 4. The highest displacement value (which is equivalent to the largest deformations in the structure area) was obtained for the case in which the structure strut was not applied (W1). It is caused by a large number of welded joints with the simultaneous lack of structural limitations. Such significant deformations are often impossible to repair, which results in the need for the scrapping of a component. With changes to the constraint method of the welded structure individual elements, the displacements value gradually decreased. The lowest value was obtained for the calculation case W5, for all mesh densities the deformation course is the same. Such behavior is a characteristic of this type of structure.

When analyzing the obtained results, it can be concluded that the compressing of the finite elements mesh density to the size of 10x10mm resulted in an increase in maximum displacements by an average of 17%. Further compression of the mesh to the size of 5x5mm slightly influenced the results, causing a significant increase in the time needed to solve the task. Taking into account the above-mentioned indicators, it can be concluded that the 10x10mm mesh allows for satisfactory results with a relatively short calculation time.

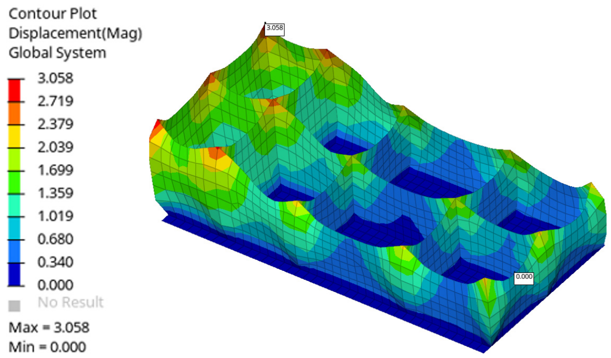
Tab. 3. Displacement distribution on the model, deformation scale 20: 1 [mm]



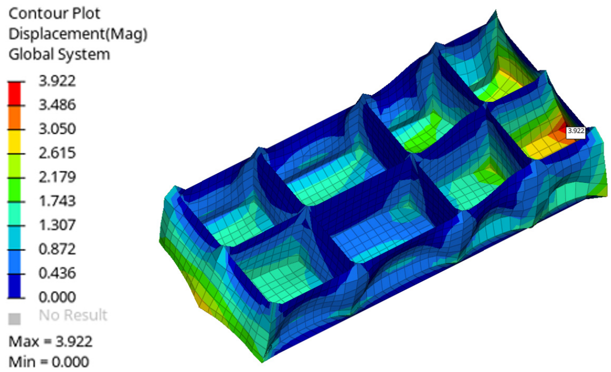
W1– Maximum displacement 6,2[mm]



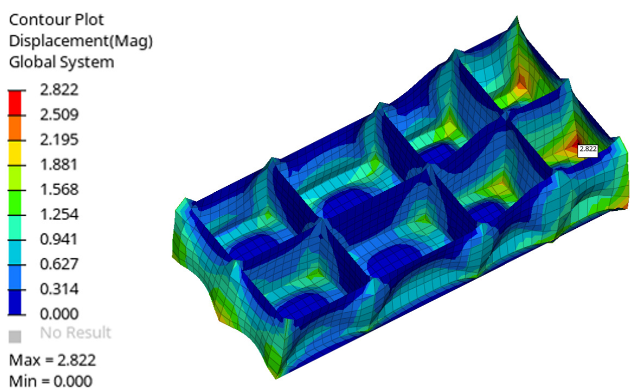
W2 – Maximum displacement 4,1[mm]



W3 – Maximum displacement 3,1[mm]



W4 – Maximum displacement 3,9[mm]



W5 - Maximum displacement 2,8[mm]

Tab. 4. The maximum displacements for different mesh densities

Mesh size	20x20	10x10	5x5
Max. disp. W1	6,2mm	7,5mm	7,6mm
Max. disp. W2	4,1mm	5,2mm	4,5mm
Max. disp. W3	3,1mm	3,5mm	3,4mm
Max. disp. W4	3,9mm	4,1mm	4,3mm
Max. disp. W5	2,8mm	3,4mm	3,1mm
Calculation time	29sec	1min 40sec	3min 21sec

5. CONCLUSIONS

On the basis of the conducted analysis, it can be concluded that the appropriate placement of the welded component plays a key role in minimizing thermal deformation, with an increase in the number of constraint points, the deformation of the structure is significantly reduced. Using the presented method, it is possible to efficiently optimize the distribution of constraint points and to choose the most advantageous variant in terms of the size of deformations and technological possibilities. Such an approach can help to minimize the risk of costly repairs and also contribute to the optimization of welding jigs. The quality requirements for welded joints do not allow for a significant change in welding parameters, which translate into heat introduced into the structure. The most effective method of minimizing thermal deformation is to use the optimal distribution of constraint points. The structure analyzed in this article is relatively small, its dimensions are 800x450x250mm. Welded structures in railway industry are very often much larger, which makes their thermal deformations much bigger. This is a very serious problem that entails enormous costs. Numerical calculations allow for highly accurate deformation simulations. The introduction of this type of simulations into the design process for low-series structures allows to avoid many problems already at the first assembly, where without additional calculations, excessive deformations would often pose a big problem, removable in a long process of real tests.

For this kind of problem, the most important is to define the methodology by which it will be possible to determine the proper behavior of the structure. The use of 2D elements allows for obtaining a sufficiently accurate solution even for relatively large structures. For the analyzed case, the 10x10mm finite element mesh provides much more accurate results than for the 20x20mm mesh. Further densification of the finite element mesh results in an increase in the calculation time with a slight change in the results, therefore this procedure seems to be economically unjustified, especially for large-size structures. The presented work results will be applied in the bio-inspired optimization of the constraints (clamps) arrangement during rail vehicles structural components welding by use of the production welding tooling. The time consuming optimization method will be more effective by use of the presented FEM analysis methodology.

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XIX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS RAILCON '20

APPLICATION OF 3D PRINTING IN RAILWAY INDUSTRY

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Aleksandar MILTENOVIĆ[2]
Dušan STAMENKOVIĆ[3]
Jovan ARANĐELOVIĆ[4]

Abstract *– In this paper, attention is focused on the application of 3D printing in railway industry based on examples that have been developed in last few years. Concrete examples of the application of 3D printing in industrial branches such as medicine, electronics, mechanical engineering, construction and railways are presented. The paper gives examples of the use of 3D printing in railways, which gives an answer especially why and in what way this type of technology is used in the railway itself, then which 3D printing are most used and which materials are currently represented in 3D printing. This paper presents examples that show the successful applications of products made with 3D printing in the railway industry, such as the wheel bearing cover, then the connecting element used in maintenance, the first approved 3D printed safety metal part for connecting the suspended brake and plastic components (cup holders, radio mounts, window frames, wiper covers and door holders).*

Keywords – 3D printing, Replacement parts, Plastic components, FDM, SLM

1. INTRODUCTION

This review aims to show the current comprehensive application of 3D printing in various industry fields as well as the application in the railway industry.

The application of 3D printing is reflected in the production of functional prototypes, spare parts, molds and tools, also Rapid prototypes are based in part on 3D printing. An analysis of the application of 3D printing will be performed through certain examples that can be found in different industry fields.

3D printing was recognized as one of the pillars of the fourth technological revolution. Currently, there are powerful companies in the market that deal with 3D printing, such as Stratasys, 3D Systems, Proto Labs, and which are trying to find a place for 3D printing on the market.

3D printing is a production method that creates three-dimensional objects by depositing material, usually by joining material layer by layer.

Most important 3D printing technologies are given in Table 1.

Tab. 1. List of 3D technologies and used materials

Technology	Used material
Stereolithography (SLA) Polyjet	Photopolymers
Fused Deposition Modelling (FDM)	Thermoplastics
Selective laser melting (SLM) Direct Metal Laser Sintering (DMLS) Electron Beam Melting (EBM) Laser Engineering Net Shape (LENS)	Metal materials
Material Jetting (MJ)	Powder materials
Binder Jetting (BJ)	Powder materials
Selective Laser Sintering (SLS)	Powder materials

The most-commonly used 3D printing process (46% as of 2018) is a material extrusion technique called fused deposition modeling or FDM. While FDM technology was invented after the other two

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most-commonly used 3D printing technologies is stereolithography (SLA) and selective laser sintering (SLS), FDM is typically the cheapest technology, which makes this process popular. Every firm that has a need for rapid prototyping acquire a FDM printer first, after which other printing technology like SLA or SLS depending on the needs of the company [1].

All reports that are dealing with 3D printing and manufacturing trends are forecasting significant growth of investment and market share. For example: The Wohlers Report 2019 forecasts for 2020 is $15.8 billion for all 3D printing products and services worldwide. The company expects that revenue forecast to climb to $23.9 billion in 2022, and $35.6 billion in 2024 [2].

2. EXAMPLES OF 3D PRINTING APPLICATIONS

2.1. 3D Printing for Medical Implants

Today, it is possible to achieve with the help of this technology, orthopedic implants (Fig.1) that are used to replace a missing joint or bone part [3].

Fig.1. Implants 3D printing using Arcam's EBM technology [3]

The advantage of this technology for medical implants is the flexibility of design, ie the manufacture of complex designs that are otherwise difficult to achieve with traditional technologies [3]. The market for orthopedic 3D printing was estimated at 691 million dollars in 2018, SmarTech analysis predicts that the value will grow to 3.7 billion dollars by 2027 [4].

2.2. 3D Printing in Electronics

3D printing as a technology is also used in the field of electronics, especially in the development and production of fast prototypes, but there are also indications that it will soon find its application in the production of functional electronic components. It is an interesting prediction that by 2029, the electronics market with 3D printing will reach a value of over two billion dollars. Development of products has been significantly accelerated, with the help of 3D printing in a matter of few hours ready-made prototypes of electronic components can be made, such as printed circuit boards, antennas, capacitors (Fig.2) and sensors [5].

Also a big advantage of 3D printing of electronic components is the possibility of miniaturization of electronic components, with increased demand with advanced functions [5].

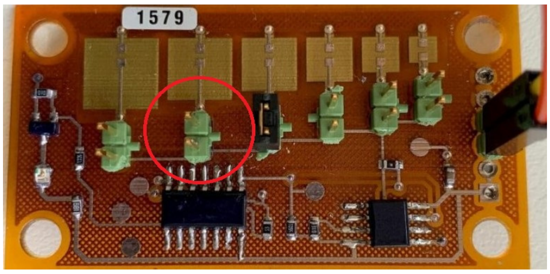

Fig.2. A 3D-printed capacitor [5]

2.3. 3D Printing for Bearings

Bearing manufacturers have also noticed 3D printing as an opportunity to develop and fabricate a better construction of the bearings themselves. By applying 3D printing, the complexity of bearing design has increased, an example being Bowman International, a bearing manufacturer that redesigned the cage to add more rolled bearing elements, resulting in increased bearing life (Fig.3) [6].

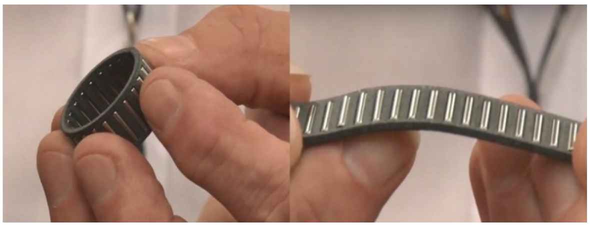

Fig.3. Cage obtained by 3D printing using flexible material [6]

2.4. 3D Printing in the construction industry

The advantage of 3D printing in the construction industry is reflected through innovative design, then in the reduction of material waste and manual labor, as well as in the faster construction of an object. One of the 3D printing technologies which is used in the construction industry is contour crafting which employs the Robotic Hand Extruder (Fig.4). This technology works similarly to FDM desktop 3D printers [7].

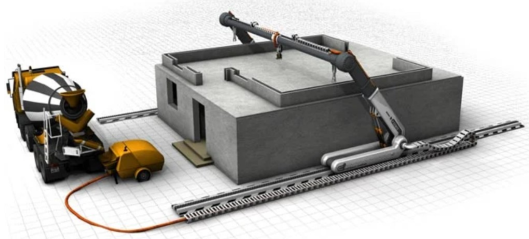

Fig.4. Contour Crafting Technology [8]

Another example is Sand 3D Printing, which is similar to 3D printing technologies such as SLS, this technology works by applying a liquid binder to the layers of powder material. Also Wire Arc Additive Manufacturing (WAAM) technology is used in the construction industry (Fig.5), WAAM works by melting metal wire using an electric arc as a heat source. WAAM equipment can work with a range of metals, such as aluminum, steel and titanium, and the technology can be used to produce large structures such as a steel bridge [9].

Fig.5. A 3D-printed steel bridge [10]

3. 3D PRINTING IN RAILWAY INDUSTRY

Companies such as Deutsche Bahn, Bombardier and Angel Trains have started investing in 3D printing in order to get to know the technology better and take advantage of its possibilities. Railway companies over time start having problems due to a lack of replacement components that were manufactured 20 to 30 years ago and for which production no longer exists. Presently it is not profitable to produce spare parts of obsolete design in small quantaties using traditional manufacturing technologies. Due to high costs, railway companies are looking for new ways to produce obsolete spare parts faster and cheaper. This is one of the main reasons why railway companies are persistently investing in 3D printing technology. 3D printers do not require specialised tools in order to manufacture products of various geometric configurations. Tool-free production can significantly reduce production time for obsolete spare parts, in some cases by as much as 95%. This way, railway companies can speed up the train maintenance process [11].

The 3D printing technologies used for railway components are mainly polymer additive technologies, such Fused Deposition Modeling (FDM) and Selective Laser Sintering (SLS). These technologies are optimized to produce parts that can function with high performance, for example by using nylon and ULTEM materials. Materials to be used for rolling stock must be covered by a certain standard EN45545-2 for industrial fire protection. Several companies offer flame-retardant thermoplastics [11].

The standard applies to manufacturers of rail vehicles, including high-speed trains, regional trains and trains in industrial transport. The following tests are used to measure product compliance with product requirements: 1. TO1 Oxygen Index; 2. 03 Flue gas density; 3. T12 Smoke toxicity. Key parameters to be measured include flame spread, flammability, heat release, smoke opacity, and toxicity [12].

Comparative properties of plastic materials used for 3D printing and traditional production methods in railways are shown in Table 2. It can be concluded that the mechanical properties of materials used in 3D printing are similar to those of materials used for traditional production methods in Railways. Which shows the possibility of applying 3D printing materials in railways from the aspect of mechanical properties.

Tab. 2. Mechanical properties [13-14]

	3D Printing materials			**Traditional materials in Railway**	
	PLA	ABS	ULTEM	SUSTAMID 6 FR (PA 6)	Maywoflamm Plus (PC/ABS Blend)
Tensile Modulus [MPa]	3039	2230	2150	3800	4650
Tensile strength, Ultimate [MPa]	48	32	69	66.5	41
Density [g/cm³]	1.24	1.05	1.34	1.17	1.35

3.1. Plastic components

Plastic components for the interior of the train such as armrests, handles, seat trays and connectors (Fig.9) can also be made by 3D printing (FDM technology) thanks to the high-temperature thermoplastic material ULTEM 9085. The production of the armrest with 3D printing took only a week, a reduction of 94% compared to conventional production methods. The Spanish manufacturer of railway vehicles, equipment and buses has produced about 2,400 3D-printed parts for use for its rolling stock, including cup holders, radio mounts, window frames, wiper covers and door holders [11].

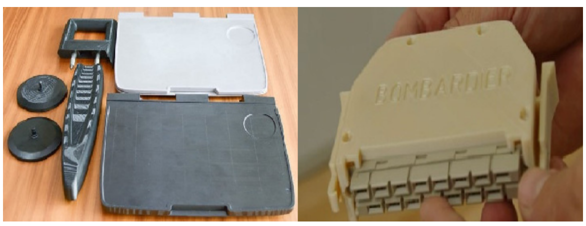

Fig.9. FDM 3D-printed parts [11]

3.2. Metal replacement parts

Deutsche Bahn has recognized the possibility of using 3D printing for more than 100 use cases. One example of such a part is the wheel bearing cover for a Class 294 locomotive. The bearing cover is made using WAAM technology which uses wire as input material. The part weighs 13 kg and was printed for a total of 7 hours (Fig.6) [11].

Fig.6. A 3D-printed near-net-shape wheelset bearing cover (left) and a post-machined part (right) [11]

Siemens Mobility has also made a connecting element used in maintenance using 3D printing. This element is very difficult to make by traditional methods, due to the complex shape (Fig.7) [11].

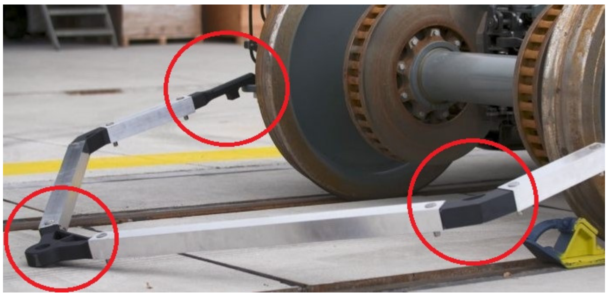

Fig.7. A 3D-printed bogie tooling [11]

3D printing has enabled Siemens Mobility to take advantage of 3D printing and replace traditional production methods for tool application [11]. By purchasing two 3D printers from the American manufacturer Stratasys, Siemens Mobility plans to use 3D printing to produce spare parts for Sapsan high-speed trains running in Russia. They will improve the maintenance operations of these vehicles [15].

Figure 8 shows the first approved 3D printed safety component for the railway sector by the German Mobility Goes Additive (MGA) network. This is a metal connection of the suspended brake, which was successfully installed on the subway of the German company Hamburg Hochbahn AG [16].

Fig.8. The approved 3D printed part [16]

4. CONCLUSION

In general, the examples given in this paper show that companies are currently trying to identify more cases in which the 3D printing can be useful, they also recognized the drastic difference in costs when it comes to making small series of parts using 3D printing compared to traditional technologies. The main reason for the application of 3D printing in the railway is the problem with obsolete spare parts and long delivery times of tools and components for end use. The result of solving this problem with the help of 3D printing is reflected in a significant drop in production costs and delivery time. It is considered that the production of additives is also a green technology, because material is a added instead of being subtracted from stock if compared to other traditional technologies. Currently, 3D printing is mainly used in maintenance, but with the potential for wider application.

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APPLICATION OF METALLOGRAPHIC TECHNIQUES IN ORDER TO IDENTIFY DEFECTS IN THE MICROSTRUCTURE OF WELDED JOINTS OF AL ALLOYS

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Abstract *- In science and practice, methods are known that can identify, with more or less success, the present defects in the welded joint. This primarily refers to cracks, pores, inclusions etc. It is also known that Al alloys are very specific for welding but also for metallographic preparation which should provide the real state of the microstructure of the tested alloy. Therefore, it is very important to choose the right procedure for specimen preparation and apply appropriate methods for observing structures under the microscope. Improper choice of these techniques can lead to wrong conclusions. The most common mistake occurs when identifying cracks. They are often confused with continuously distributed intermetallic phases (IMP) at the grain boundaries or dendritic cells. The purpose of this paper is to use the example of butt welded joint (MIG process) Al alloy EN AW 6005 (t=3mm) and EN AW 6082 (t=23mm) with filler wire S-Al 5183, to show the possibility of applying different specimen preparation procedures, methods and magnification in microscope to identify cracks. Etching of specimen in Keller's reagent and anodic oxidation in Barker's reagent were applied. The bright field of the microscope and polarized light were used. The combination of anodic oxidation in Barker's reagent with observation in the bright field of a microscope and with optimal magnification proved to be the most reliable technique for crack detection.*

Key words - welded joint, Al alloys, metallographic preparation, wagon structure, cracks.

1. INTRODUCTION

Al alloys, especially the 6xxx and 5xxx series are widely used in the construction of rail vehicles (trams, trains, etc.), due to the need to increase speed and transport capacity, as well as to reduce maintenance costs, which is made possible by their properties. The 6xxx series alloys are strengthen by heat treatment.
They belong to the group of Al alloys of medium strength with good weldability and corrosion resistance. They also have an outstanding ability to be shaped by extrusion and pressing, from simple to complex profiles [1,2]. Alloys 6082 and 6005, which are the subject of this paper, are among the most widely used alloys in the rail industry. Their tendency to the appearance of hot cracks and the influence of different parameters on this undesirable defects were specially investigated [3]. Sensitivity to the appearance of defects primarily depends on the chemical composition, welding process, preheating, type of filler wire, the occurrence of internal stresses, cooling rate, etc. These facts include WM, HAZ and BM [3]. In case of cracks, it is very important to identify them in the microstructure and determine the cause of their occurrence on the basis of appearance and position. For this, specimen preparation is very important, as well as the application of an appropriate method and, in particular, magnification on a microscope [4]. This welded joint is one of the most important joints on the entire construction of the wagon structure. It is a part of the side beam of the floor of the wagon, which represents the supporting structure.

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2. EXPERIMENT

Alloys 6005A (BM1), 3mm thick, and 6082 (BM2), 23mm thick were used for testing. They were butt-welded by the MIG process (En ISO 4063).

On a Kemppi X8 welding machine, No.2709979, in a shielding gas atmosphere of 13-Ar-He-30, in five passes. Filler wire was the S-Al 5183. The appearance of the welded part is shown in Fig. 1. Microstructure testing was performed on the cross section of the specimen after the usual metallographic preparation (cutting, grinding, polishing and etching) in the areas of both base materials (BM1 and BM2), HAZ and weld metal (WM).

Since the purpose of the paper was to determine which specimen preparation technique most reliably identifies the presence of defects, primarily cracks, several combinations were performed.

In the first, after polishing, the specimen was etched in Keller's reagent and examined in a bright microscope field.

In another combination, the specimen is electropolished and subjected to anodic oxidation in Barker's reagent. This specimen was examined normally in polarized light and then (third combination) in the bright field of a microscope.

All these tests were performed on a Leica DM4 M optical microscope at different magnifications, in order to determine which specimen preparation gives a realistic appearance of the present defects.

3. RESULTS AND DISCUSSION

By detailed analysis of the microstructure of the welded joint, after etching the specimen in Keller's reagent, Fig.2., after anodic oxidation in Barker's reagent and observation in a bright field microscope, Fig.3., and examining the same specimen in polarized light, Fig.4., cracks can be found on both sides of the weld. The cause of cracks is certainly a consequence of different cooling rates caused by a large difference in the thickness of the welded parts.

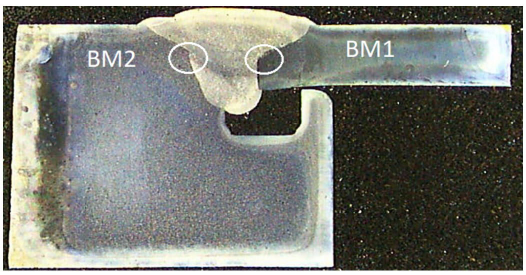

Fig.1. Macrostructure of the welded joint and positions of microstructure testing

This caused high internal stresses which are especially dangerous if they are tensile. If they exceed the tensile strength value material start to stress relief, which happened here as well. In Fig.2., lines are clearly visible, on both sides of the weld, which may indicate cracks. They start in the columnar crystals zone in WM and continue to spread, via HAZ, towards the base material.

They follow the boundaries of grains and dendrites, which are the weakest places due to distributed, hard and brittle, IMP particles. Since the IMP is being distributed along these boundaries, and they look similar, there may be confusion. Therefore, it is necessary to apply other techniques and methods to make sure that it is a crack.

a)
b)
c)
d)

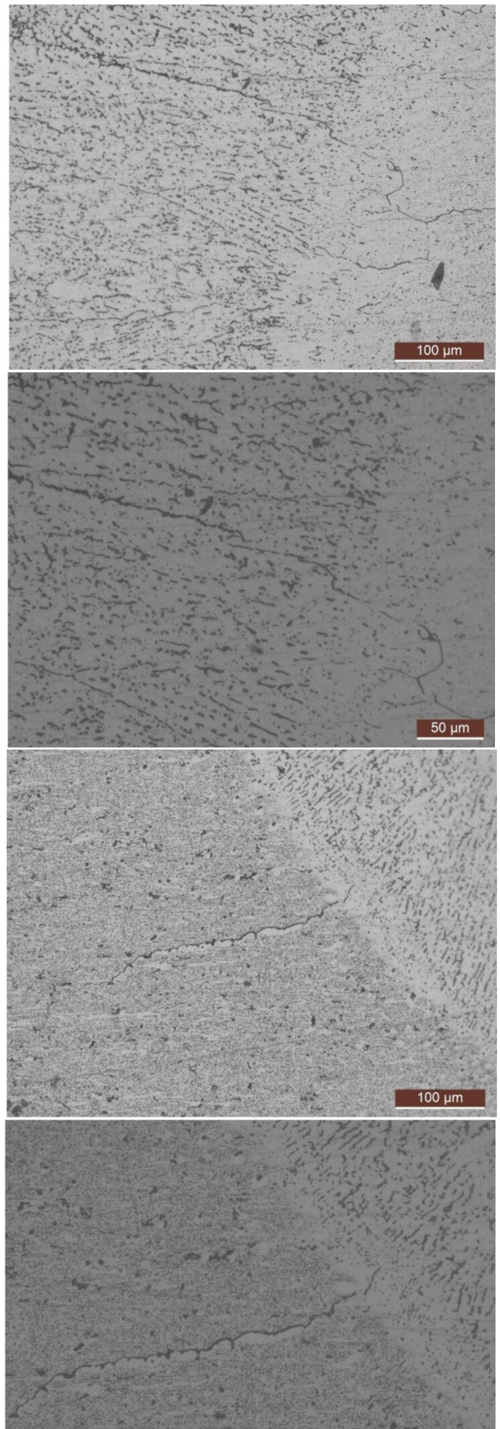

Fig.2. Microstructure of welded joint, on the side of BM1 (a,b) and BM2 (c,d);Keller's reagent, bright field

Microstructure analysis was performed by observation in a bright field of microscope, Fig.3. Cracks were found, with certainty, on both sides of the weld. It is obvious that they start in the zone of columnar crystals and spread through the HAZ (Fig.3.a, b-BM1) along the boundaries of the dendritic cell. This is only clearly seen at a magnification of 500x, Fig.3.b.

a)

b)

c)

d)

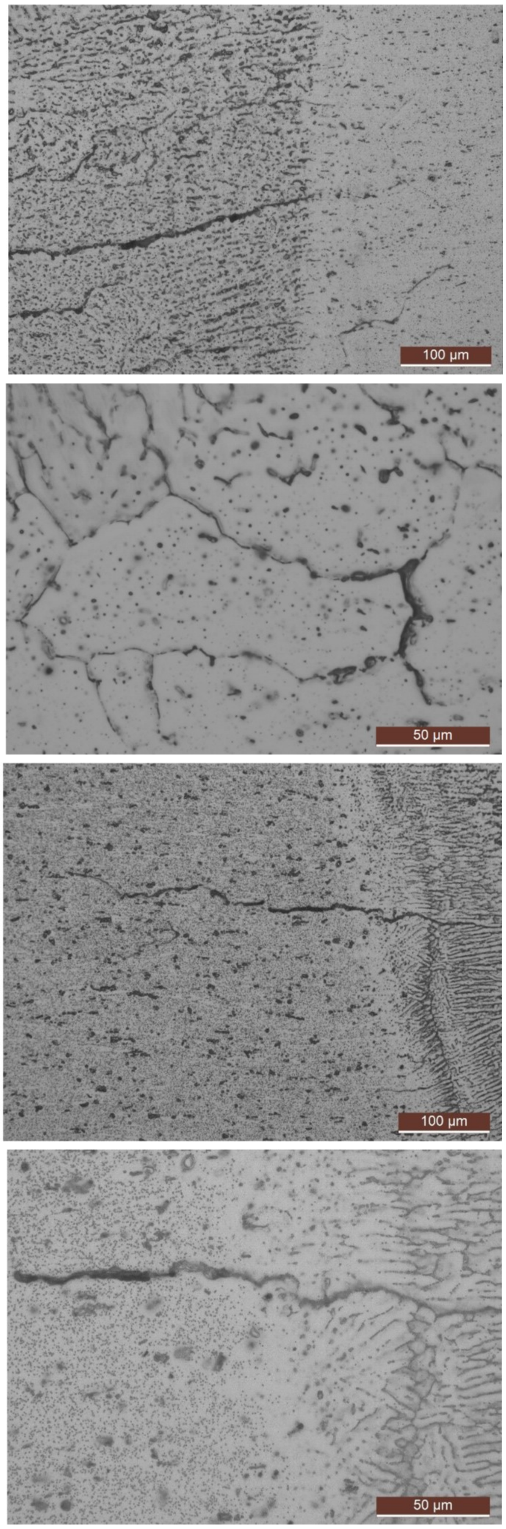

Fig.3. Microstructure of welded joint, on the side of BM1 (a,b) and BM2 (c,d);Barker's reagent, bright field

On the side of the BM2 (6082) crack, it also starts from the columnar crystal zone, where the highest concentration of IMP is and spreads deep into the base material, Fig.3.c, d.

By analyzing the same specimen in polarized light, the grains, their shape and size are clearly visible, Fig.4. However, the presence of defects is less noticeable due to the high probability that hard IMP particles will fall out during specimen preparation. At that place there is a hole which, in polarized light, shines, Fig.4, a and b. On the same figures, a crack in the form of a light line can be seen, on the BM1 side, but only thanks to the fact that it was previously identified by observation in a bright field, Fig.3.

The existing crack on the BM2 side is not visible at all.

a)

b)

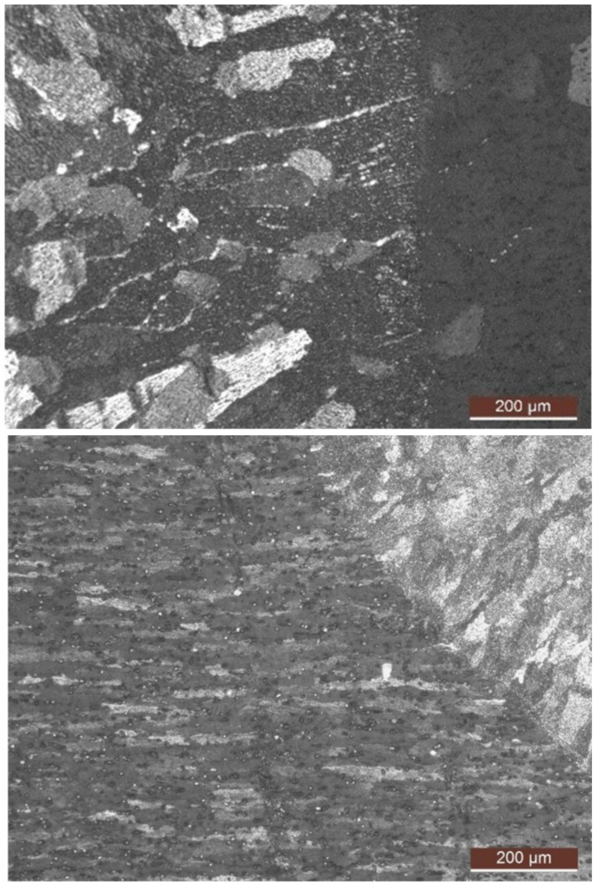

Fig.4. Microstructure of welded joint, on the side of BM1 (a) and BM2 (b);Barker's reagent. polarized field

4. CONCLUSION

Based on a detailed microstructural analysis of a welded joint specimen, prepared by various metallographic techniques, it can be concluded that the most reliable crack detection technique proved to be a combination of anodic oxidation in Barker's reagent with bright field microscopy at optimally selected magnification.

ACKNOWLEDGEMENT

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XIX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
RAILCON '20

ANALYSIS OF LOGISTICS CHAINS, SERVICED BY RAILWAY TRANSPORT AND APPROACHES FOR TECHNOLOGICAL DESIGN OF PROCESSES

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Abstract *– The diversity of logistics chains that provide the transfer (transit) of material resources from one logistics system to another one requires a different approach to their description and design. Industrial railway branches (industrial railway terminals) are points providing logistical operations between railway undertakings or shunting operators and the industrial systems of the various sectors of the national economy. They are the main unit of the logistics chains that use the railway transport, connecting the national railway network with the transport systems of specific production facilities, ports, intermodal transport terminals, etc., providing direct transport service between consignor - consignee without additional operations and unnecessary costs of time and resources. The presented analysis describes the approaches in technological design of the processes of the most common cases related to different logistics activities. The purpose is to define the problem, to formulate the tasks for solving it and choose the approach in determining the resource and organization of the transport service. Various variants of solutions related to port complexes, industrial objects of energy, metallurgical and chemical industries are analyzed, as well as such servicing logistic centers, manufacturing enterprises and sites with inconsistent and small wagon flow.*

Keywords – logistics, railway transportation, optimization, technology.

1. INTRODUCTION

The diversity of logistics chains ensuring the transition of freight from one logistics system to another requires a different approach to their description and design in order to synchronize the activities of different modes of transport (transport operators, carriers, freight forwarders and companies). The organization of transport processes in the choice of mode of transport can use different options influenced by the characteristics of transport flows and their purpose. The criteria of the users of the transport service, such as minimum transportation costs, also have an impact; delivery time; maximum reliability and safety; access to a certain type of transport and others. Depending on the characteristics and areas of effective application of different modes of transport, it is possible to build different transport systems, taking into account the specifics of transport and making the most of the advantages of a particular mode of transport for a particular logistics chain. The spheres of effective application of railway transport (mass loads over medium and long distances, dangerous goods and those that originate and extinguish directly in industrial railway terminals) make it indispensable in serving certain industries [1].

Industrial railway branches (IRB) are points providing logistics operations between railway undertakings or shunting operators and the industrial systems of the various branches of the national economy. They are the main unit of the logistics chains using railway transport, connecting the national railway network with the transport systems of specific industries, ports, terminals for intermodal transport and others. In the national railway network most of the (main) freight is loaded and repaid in IRB. Their main advantage is that they provide direct transport services between producer and consumer (shipper - consignee) without additional operations and unnecessary costs of time and money at the points of transhipment or interaction between modes of transport. This has led to the development and diversity of the IRB network, which in most cases are subsystems of powerful logistics chains.

The objective of the present analysis are logistics chains served by railway transport. The methods for

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their sizing (determination of the technological parameters and the resource for customer service) depending on the characteristics and limitations of deterministic and stochastic processes.

2. MAIN PARAMETERS AND RELATIONS OF THE PROCESSES IN THE LOGISTICS CHAIN

Optimizing the technology of work in different systems requires typification and classification of the main objects involved in the process and differentiation of the approach in their design. The solution to this problem is performed in the following sequence:

• Determining the type, characteristics, participants and functional scheme of the processes with the respective time parameters and dependencies between National Railway Infrastructure Company (in Bulgaria) (NRIC) and the railway carrier (operator).

• Selection of a methodology for determining the technological parameters and development of Unified Transport Technology (UTT). The process is unified for the different participants in it (NRIC, railway carrier, industrial transport operator, port operator, etc.), as it subordinates the activities in the different subsystems to a single (synchronized) mode of operation.

• The third step includes regulation of the activities in the logistics chain related to the railway transport and preparation of a contract for operation of IRB and customer service.

3. VARIANTS OF SOLUTIONS DEPENDING ON THE TYPE OF LOGISTIC ACTIVITY AND APPROACHES FOR SIZING THE LOGISTICS CHAIN

The classification of logistics chains served by rail can be structured on several principles, the main ones being the type of industry it serves, the volume of freight flows and their unevenness in annual terms, the possibility of competitive traffic services from other modes of transport and the number of industrial carriers. areas and logistics centers. The most common are:

A) Port complexes and specialized quays of various industries

They are characterized by powerful and diverse freight flows, as well as a rich nomenclature of freight rolling stock. The sequence in developing the organization of work is reduced to:

Determining the maneuvering areas for the work of the brigades by specifying their activity in accordance with the normative documents. Description of the shunting operations for servicing a specific pier, speed in the area; providing braking mass of the shunting train and order for feeding / removing the groups of wagons in accordance with the technological map for operation of the quay. The places for commercial and technical inspection of the wagons, their enrollment and other operations for cleaning, disinfection, measurement are regulated. The number of shunting brigades working in shifts and the order of passage in the zones of enemy movements (routes) are determined. In the functional analysis the specialization of the shunting brigades by port areas is made in order to improve the railway service in accordance with the specifics of the served cargo flow (quay) [2]. The industrial railway branches serving the energy sector - provide mainly transportation of energy and raw materials accompanying the processes (coal, fuel oil, various fractions of limestone, etc.).

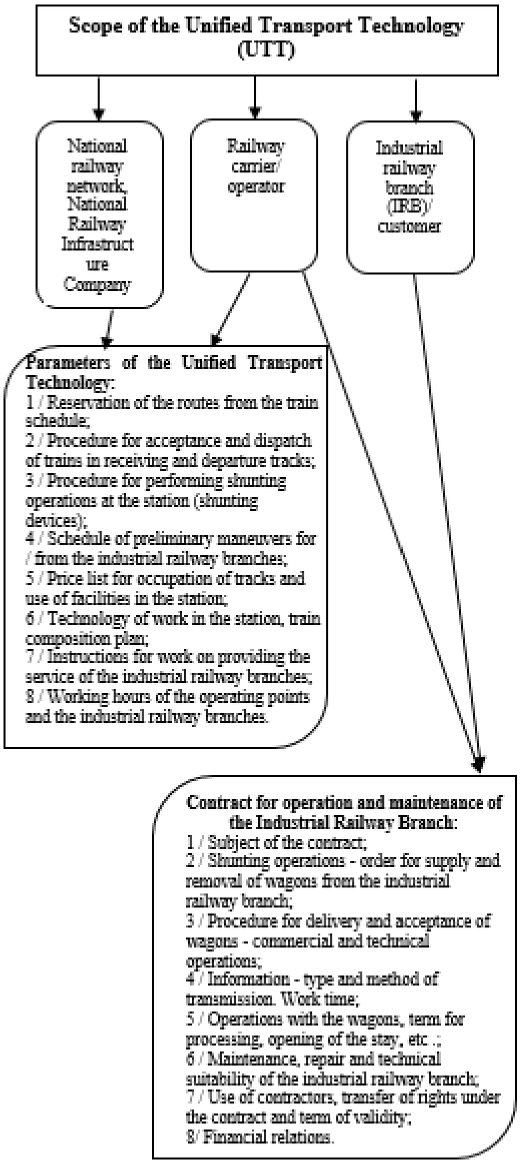

Fig. 1 Main parameters and links of the processes in the logistics chain

Due to the continuous character of the production processes and the high degree of reliability in the management of supply chains, the transport process in the industrial zone can be defined as determined, and railway transport can be designed depending on the constraints of the logistics chain and the phases through which the freight flow passes. [3]. This requires research and analysis of unmanageable parameters influencing the processes related to the study of input flow intensity, irregularities in the interval and volume of entry, duration of processing of groups of wagons and others, which allows for an accurate description of the process. It can be presented as a queuing system or by simulation modeling to determine the resources for its provision.

B) Industrial railway branches and industrial stations of the metallurgical industry

They are characterized by active incoming and outgoing freight flows, (raw materials and finished products) [4].

The technological description of the activities and their synchronization along the supply chain requires the different time and resource parameters to be determined in the different states that the system can occupy. These conditions examine the unevenness of the IHC inlet for the period of maximum load. On this basis, a general concept for the operation of the system is developed by providing the necessary reserve of capacity and resources for different service options. The problem-solving model is presented as a queuing system (QS), implemented through a developed simulation model based on the GPSS language (General Purpose Simulation System) [5].

The specific model allows the reproduction of various technological solutions, such as the export of the main stocks of raw materials in the port complex and regular supply to the network of the main railway transport. The large capacity of the docks in the bulk cargo terminal in the port creates prerequisites for a smooth process in the transportation of raw materials and work on a fixed schedule in the highway transport. This, in turn, improves the conditions of entry into the industrial units of the transport system and ensures the necessary reliability, with significantly lower resource provision.

C) Logistics chains of the oil refining and chemical industry

They are characterized by increased requirements for security and safety of transport.

Several railway service systems can be considered here. The first are related to the service of oil derivatives, gas and chemicals from terminal to terminal, without being part of a chain for distribution and sale of material resources on the market. They apply the conventional methods of technological design, as in all IRB with the corresponding irregularities and delays of the processes within certain limits regulated in the service contracts between the railways. carrier and customer (owner of the railway branch). In another case, logistics management covers all activities in a corporate supply chain for the delivery and distribution of petroleum products, which are owned by the port terminal, the regional distribution base, a chain of petrol stations, rail transport and specialized road transport [6]. This means that the subject of research and optimization are parameters external to the chain that we cannot influence with management decisions. Such are the deliveries and operation of the maritime transport at the entrance of the logistics chain, as well as the railway carrier as a connecting link between the port and the distribution terminal (Fig. 2).

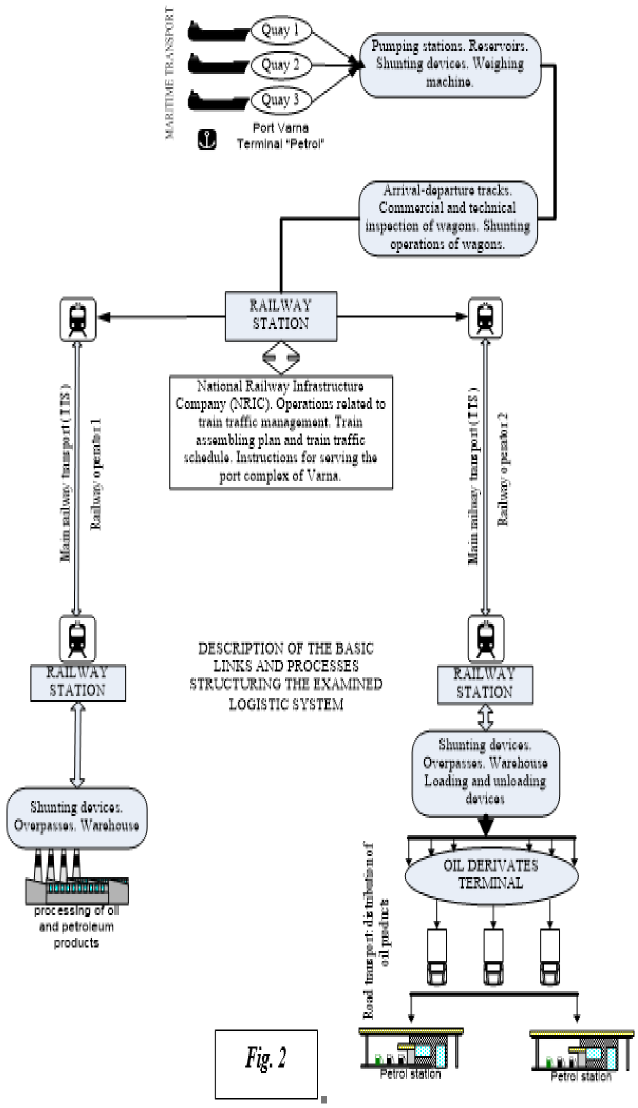

Fig. 2. The basic links and processes

In this case, the railway transport and the options for operation in various process irregularities are studied in detail and described in [7]. The narrow place in the logistics chain is the rate of realization of oil derivatives, their unevenness, the rhythm (frequency) of refueling at gas stations and determining the necessary stocks of products in the regional terminal. The goal is not to refuse customer service due to lack of derivative at optimal costs. This optimization process requires detailed market research by regions in which the corporate chain operates.

Algorithm for achieving the goals:

- ***Step 1.*** Research, analysis and structure of the logistics chain. Description of the process.
- ***Step 2***. Analysis of the random parameters influencing the operation of the entrance of the logistics chain - maritime transport (intensity of the incoming flow, irregularities in interval and volume of arrival, duration of processing of ships).
- ***Step 3*** Implementation of the process for technological design of the transport system port - rail transport - terminal of oil derivatives (delivery time, schedule for operation in the terminals (industrial railway branches), train schedule, number of trains, gross mass of trains trains, number of locomotives, wagon fleet, etc.).

D) Industrial railway branches serving retail chains, distribution centers, manufacturing plants and sites with intermittent and low wagon traffic

In this type of industrial systems, the technology and organization of railway transport is described in the instructions for servicing the specific industrial railway branch in accordance with the technology of operation in the interacting station, and the actual process is managed operationally through round-the-clock and shift operational plans. Emphasis is placed on the procedure for servicing industrial railway branches by carriers in case there are more than two. [8]

The logistics systems described above are the most common actively served by railway transport and form more than 80% of the tonne-kilometer work in the national railway network.

4. CONCLUSION

The presented analysis describes the approaches in technological design of the processes of the most common cases related to different logistics activities. The purpose is to define the problem, to formulate the tasks for solving it and choose the approach in determining the resource and organization of the transport service. Various variants of solutions related to port complexes, industrial objects of energy, metallurgical and chemical industries are analyzed, as well as such servicing logistic centers, manufacturing enterprises and sites with inconsistent and small wagon flow.

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THE REVIEW OF HARMONIZED STANDARDS OF PERSONAL PROTECTIVE EQUIPMENT FOR SAFE WORK ON RAILWAY

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Abstract *– Using of personal protective equipment (PPE) is often essential, but it is generally the last line of defense after engineering controls, work practices, and administrative controls. Working in the rail industry encounter many hazards, as could be expect in any heavy industry. However, there are additional hazards that are specific to the rail industry as a cosequence of activities such as working around electrical cables at a substation or any equipment connected to the system, working around overhead wiring structures, near substation cables connect to the rails, working with cranes, elevating platform vehicles, tip trucks or other plant. As required by the harmonized standards (the new PPE Regulation 2016/425 took effect on April 20, 2016 instead of the old PPE Directive 89/686 EEC for the testing and certification of personal protective equipment), PPE must be selected which will protect employees from the specific hazards which they are likely to encounter during their work on-site.Selection of the appropriate PPE is a complex process which should take into consideration a variety of factors. Key factors involved in this process are identification of the hazards, or suspected hazards; their routes of potential hazard to employees, the performance of the PPE materials (and seams) in providing a barrier to these hazards. Other factors in this selection process to be considered are matching the PPE to the employee's work requirements and task-specific conditions. The site information may suggest the use of combinations of PPE selected from the different protection levels (i.e., A, B, C, or D) as being more suitable to the hazards of the work. In this paper we presented harmonized regulation for PPE for different protection levels, as well as standardized methods for PPE testing.*

Key words − Personal protective equipment, harmonized standards, railway, testing methods

1. INTRODUCTION

Occupational safety and health (OSH) is concerned with preserving and protecting human and facility resources in the workplace helping people by preventing them from being injured or becoming ill due to hazards in their workplaces. Occupational safety and health is an extensive multidisciplinary field, invariably touching on issues related to scientific areas such as medicine – including physiology and toxicology, ergonomics, physics and chemistry, as well as technology, economics, law and other areas specific to various industries and activities. Despite this variety of concerns and interests, certain basic principles of OSH including decent working conditions and a decent working environment. More specifically work should take place in a safe and healthy working environment; conditions of work should be consistent with workers' well-being and human dignity; work should offer real possibilities for personal achievement, selffulfilment and service to society [1].

"Occupational health should aim at: the promotion and maintenance of the highest degree of physical, mental and social well-being of workers in all occupations; the prevention amongst workers of

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departures from health caused by their working conditions; the protection of workers in their employment from risks resulting from factors adverse to health; the placing and maintenance of the worker in an occupational environment adapted to his physiological and psychological capabilities; and, to summarize: the adaptation of work to man and of each man to his job" [2].

Personal Protective Equipment (PPE), are the tools that ensure the basic health protection and safety of users. PPE is any device or appliance designed to be worn by an individual when exposed to one or more health and safety hazards. PPE includes all clothing and other work accessories designed to create a barrier against workplace hazards, and using PPE requires hazard awareness and training on the part of the user. Employees must be aware that the equipment does not eliminate the hazard; if the equipment fails, exposure will occur. To reduce the possibility of failure, equipment must be properly fitted and maintained in a clean and serviceable condition.

2. OCCUPATIONAL SAFETY AND HEALTH HAZARDS IN RAILWAY INDUSTRY

Occupational safety and healt in railway industry are applicable to activities typically conducted by rail infrastructure operators dedicated to passenger and freight transport. OSH cover two main areas, namely rail operations, covering construction and maintenance of rail infrastructure as well as operation of rolling stock, and, locomotive maintenance activities, including engine services, and other mechanical repair and maintenance of locomotives and railcars.

Occupational health and safety hazards during the construction of railway systems are common to those of most large industrial facilities and their prevention and control additional health and safety issues specific to railway operations include the following:

- Train / worker accidents,
- Noise and vibration,
- Diesel exhaust,
- Fatigue,
- Electrical hazards,
- Electric and magnetic fields.

Railway workers, including locomotive crews and workers in stations, rail yards, and locomotive and car shops, may be exposed to exhaust from diesel locomotives and other diesel engines. Crew members riding immediately behind the lead engines of trains (e.g. trailing locomotives) and workers in indoor turnaround areas where locomotives are usually left operating, sometimes for prolonged periods, may be exposed to particularly high levels of diesel exhaust.

Occupational hazards typically associated with locomotive and railcar maintenance activities may include physical, chemical, and biological hazards as well as confined space entry hazards. Physical hazards may be associated with work in proximity to moving equipment (e.g. locomotives and other vehicles) and machine safety, including work-portable tools, and electrical safety issues [3].

Chemical hazards may include potential exposures to a variety of hazardous materials (e.g. asbestos, PCB, toxic paint, heavy metals, and VOCs, including those resulting from the use of solvent-based paints and cleaning solvents in enclosed spaces). Other chemical hazards may include the potential for fire and explosion during the conduct of hot work in storage tank systems [4,5].

Biological hazards may include potential exposures to pathogens present in sewage storage compartments [6]. Confined spaces may include access to railroad tank and grain cars during repair and maintenance.

Dangerous goods are frequently transported in bulk orpackaged form by rail, representing a potential risk of release to the environment in the event of accidents on a number of other causes. Examples include valve leakage or safety valve releases in pressurized and general-service tank cars or other hazardous material containers (e.g. covered hoppers, intermodal trailers and containers, or portable tanks). In intermodal containers, spills and leaks may result from improper packing and resultant load shifting during transport. Additionally, there is a potential for the release of diesel during fueling operations.

2. PERSONAL PROTECTIVE EQUIPMENT UNDER REGULATION (EU) 2016/425

The PPE Directive was one of the first New Approach Directives and is now over 20 years old. PPE is currently regulated by Directive 89/686/EEC. In order to reflect current technologies and processes for developing and bringing PPE to the market, it is in the process of being superseded by a new PPE Regulation (EU) 2016/425 Within the European Union.

It covers most domestic, leisure and professional safety products, requiring all PPE products to meet Basic Health and Safety Requirements (BHSR), [7]. PPE products are classified into one of three categories, depending upon the level of risk associated with their use.

Category I - PPE in this category is designed to protect users against minimal risks. These include superficial mechanical injury; contact with water or cleaning materials of weak action; contact with hot surfaces not exceeding 50°C; damage to the eyes due to exposure to sunlight (other than during observation of the sun); atmospheric conditions that are not of an extreme nature.

Category II - includes risks other than those listed in Categories I and III. The following products are included: Safety spectacles and goggles, Industrial helmets and bump caps, hi visibility clothing, etc.

Category III - PPE falling under this category 'includes exclusively the risks that may cause very serious consequences such as death or irreversible damage to health' Risks include: substances and mixtures which are hazardous to health; atmospheres with oxygen deficiency; harmful biological agents; ionising radiation; high-temperature environments the effects of which are comparable to those of an air temperature of at least 100 °C; low-temperature environments the effects of which are comparable to those of an air temperature of – 50 °C or less; falling from a height; electric shock and live working; drowning; cuts by hand-held chainsaws; high-pressure jets; bullet wounds or knife stabs; harmful noise.

4. PERSONAL PROTECTIVE EQUIPMENT (PPE) DIRECTIVE (89/686/EEC)

High visibility products fall within the jurisdiction of the Personal Protective Equipment (PPE) Directive (89/686/EEC) and are intended to signal the wearers' presence visually in different light conditions and make the wearer stand out from the surrounding environment. Currently there are two standards for visibility clothing and one for accessories published as Harmonized Standards in Europe. For visibility clothing, there are defined areas of fluorescent background fabric and retro-reflective material. There are also requirements for the placement of both to ensure there is 360° visibility and that the human form is recognisable. Both standards for visibility clothing ensure enhanced visibility during daylight conditions (i.e. by the use of fluorescent fabric) and also in poor lighting or in darkness (from utilising retro-reflective material).

4.1 EN ISO 20471:2013 High Visibility Clothing

The wearing of high-visibility clothing is a mandatory requirement for all persons associated with track or lineside working. Railway workers may find themselves carrying out maintenance work on track, where no trains are running – called 'green zone working'. However, much work is undertaken on active railways, during day and night, and under different weather conditions. Under such circumstances (known as 'red zone working'), the dangers are real and ever-present, and it is important that the highest levels of visibility are maintained.

The main feature of high-visibility clothing is that it is made from materials that aid conspicuity by day and night. To enhance the visibility of a wearer during the day, garments are made from fluorescent materials of standard colours. The visibility of a person is aided at night by the inclusion of retro-reflective tapes within the construction of a garment. Retro-reflective materials reflect a high proportion of light back towards its point of origin.

"EN ISO 20471:2013 High visibility clothing" was published on the 1st March 2013 and was subsequently issued as BS EN ISO 20471 in July 2013 incorporating a corrigendum. It became a harmonized standard on 28th June 2013. EN 471:2003 + A1:2007 was withdrawn on 1st September 2013.

This standard specifies the requirements for clothing intended to provide conspicuity of the wearer in any light condition. Under daylight conditions, fluorescent high visibility material is used, which provides a high level of contrast between the product and the environment in which it is to be worn. The situations in which high visibility clothing to EN ISO 20471 is worn are classed as 'high risk' and this standard is not applicable to medium-risk and low-risk.

This standard gives performance requirements for the colour and retro-reflection, as well as, for minimum areas and the placement of the fluorescent and retro-reflective materials. There are only three colours specified – fluorescent yellow, orange-red and red. There are also requirements for the colour fastness, dimensional stability, strength and the water vapour resistance of the fluorescent and any non-fluorescent materials. The retro-reflective material is tested for photometric performance as new and after a number of pre-treatments.

4.2 Fabrics

The background fabrics must now meet the chromaticity and luminance after the maximum number of cleaning cycles (or if this is not stated by the manufacturer a minimum of 5 cycles). Colour fastness to perspiration (staining) is Grade 4 (both fluorescent and non-fluorescent materials). Colour fastness to washing/dry cleaning has had the staining requirement reduced to 4 for non-fluorescent fabrics.

For fabrics other than coated/laminates, the water vapour resistance must be less than 5 m^2Pa/W. If this is exceeded, then the thermal resistance must be tested and the water vapour permeability index (WPI) determined. The WPI must be ≥ 0.15. Tabards and waistcoats are exempt from this requirement. Contrast (non-fluorescent) outer materials must now meet the mechanical property requirements. Colour fastness to hot pressing is only required in the dry condition only.

4.3 Retro-reflective material

Retro-reflective material must now be tested after a stated number of wash/dry cycles rather than the maximum number of wash cycles with one dry at the end. If the maximum number of wash cycles is not stated by the manufacturer, the retro-reflective material must be tested after a minimum of 5 cycles. The wash temperature can be specified by the manufacturer.

5. HIGH VISIBILITY PPE CERTIFICATION PROCESS

For all categories of PPE, the manufacturer must provide information about the measures it has taken in order to ensure the conformity of the PPE to the Basic Health and Safety Requirements (PPE Directive (89/686/EEC) Annex II) in technical documentation. For intermediate and complex category products, the technical file and the product it covers must be examined by a Notified Body for Type Approval. If the product and technical documentation meet all the requirements, the Notified Body will issue an EC Type Examination Certificate. This certificate allows the article to be CE marked. For complex category products, on-going surveillance is also required.

High visibility PPE falls within the category II or intermediate category and therefore requires an EC Type Examination. For high visibility clothing, it is common practice for the suppliers' of the fabrics and retro-reflective tape to get their products tested. The garment manufacturers can then use the suppliers' test reports or test certificates for certification purposes without testing these components themselves. If the suppliers have not had their products tested, the garment manufacturer will have to commission this testing. The test reports for the components are given as part of the technical documentation to the notified body along with samples of the clothing.

6. CONCLUSION

The purpose of personal protective clothing and equipment (PPE) is to shield or isolate individuals from the chemical, physical, and biologic hazards that may be encountered. Careful selection and use of adequate PPE should protect the respiratory system, skin, eyes, face, hands, feet, head, body, and hearing. No single combination of protective equipment and clothing is capable of protecting against all hazards. Thus PPE should be used in conjunction with other protective methods. In general, the greater the level of PPE protection, the greater are the associated risks. for any given situation, equipment and clothing should be selected that provide an adequate level of protection.

ACKNOWLEDGEMENT

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[8]

NOVEL RECOMMENDATIONS OF UIC FOR CALCULATION OF CARBON CONTENT IN RAILWAY INFRASTRUCTURE

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Abstract – *The quantifaing carbon emissions from the rail sector has a long history because railways are among the all transport modes, one of efficient modes of carbon mass transportation. According to UIC's recomendations all rail operators need to lowering the carbon impact of the railway sector. The most approaches are harmonized except evaluation and estimation of the carbon content of the railway infrastructure over its life cycle. The aim of this paper is to present novel UIC's recomendation for evaluation the carbon footprint of railway infrastructure. The novelty of the carbon footprint estimation is consideration of building and maintance of railway infrastructure and construction vehicles/machines used for those purpose that usually emit significant amounts of carbon. Also we discused the role of certification process,i.e. the necesserity of implementation regulations such as ISO 14064 standard that provides set of tools for programs to quantify, monitor, report and verify greenhouse gas emissions.*

Key words – Carbon footprint, railway infrastructure, methods.

1. INTRODUCTION

Greenhouse gaseous GHGs are constituent of the atmosphere, both natural and anthropogenic, that absorbs and emits radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere, and clouds. CO_2 is the major greenhouse gas contributing to global warming and climate change; it is emitted by both natural and anthropogenic sources.

The Kyoto Protocol [1] regulates five GHGs beside carbon dioxide: methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6).

The Intergovernmental Panel on Climate Change (IPCC) [2] claims that warming of the climate system “is unequivocal”. Global greenhouse gas (GHG) emissions [3] due to human activities have grown since pre-industrial times, with an increase of 70 % between 1970 and 2004 alone. This development has led to clear changes in temperatures. An additional temperature rise of between 1°C and 4°C is projected between 2000-2100, depending on the level of stabilization of GHG emissions.

The transport sector is projected to remain the fastest growing sector when it comes to CO_2 emissions. Green house gases are generated from all types of railway locomotive and diesel combustion contributes the maximum. Emissions from an individual railway locomotive will depend on the fuel used, full carbon content of the fuel, distance travelled, cargo load, passenger load and engine efficiency. In the context of increasing global awareness of anthropogenic climate change, the carbon footprint concept is now widely used both as a marketing tool and to mobilize public sentiment. The Europian Investment Bank (EIB) considered carbon footprint methodology as “work in progress” that is subjected to periodic review and revision in the light

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of experience gained and as knowledge of climate change issues evolves [4].

The railways are one of the most environment-friendly means of transport. Modal shift towards rail transport can be an appropriate measure for reducing energy consumption, CO_2 emissions, pollutants and noise. The advantages of rail transport are most prominent in terms of energy efficiency and reduction of environmental impact.

In the case of passenger transport, the railways emit less CO_2 than, for example, private cars by a factor of between 2 and 4, depending on the concrete technology, the occupancy rate, and the energy mix in the catenaries [5]. Therefore, modal shift towards the railways is an important means of climate policy. However, the railways themselves can also become more efficient in terms of energy consumption and CO_2 emissions. Reducing the CO_2 emissions of the railways directly contributes to climate protection.

2. ENERGY CONSUMPTION AND CO_2 EMISSIONS

Energy consumption is directly connected with GHG emissions that are expressed via CO_2 emissions or total carbon emission.

After carbon dioxide, black carbon[1] has the second biggest impact on climate forcing in the atmosphere. Black carbon typically remains in the atmosphere for days to weeks, until it returns to the earth's surface through rain or air deposition [6-9]. Carbon dioxide, in contrast, stays in the atmosphere for decades. While in the atmosphere, black carbon has over 3,000 times the global warming potential (GWP) of carbon dioxide, black carbon has a number of harmful qualities, but also the potential for reduction. On a global scale, the largest sources of black carbon are open burning of grasses, woodlands and forests (as well as agricultural fields to a lesser degree), residential heating and cooking (primarily from wood fires), and diesel engines [10].

The primary sources of carbon black are on-road and off-road diesel engines. On-road diesel engines include diesel trucks, cars, etc. Off-road diesel engines include locomotives and other heavy-duty equipment, thus the share related to freight transport (e.g., trains, ships, agricultural and construction equipment, generators, etc.).

[1] Black carbon is a distinct type of carbonaceous material that is formed primarily in flames, is directly emitted to the atmosphere, and has a unique combination of physical properties. It strongly absorbs visible light, is refractory with a vaporization temperature near 4000 K, exists as an aggregate of small spheres, and is insoluble in water and common organic solvents. Sources whose emissions are rich in black carbon ("BC-rich") can be grouped into a small number of categories, broadly described as diesel engines, industry, residential solid fuel, and open burning.

Railway specific energy consumption and specific CO_2 emissions are mainly based on UIC data. The railway companies provide UIC with their tractive stock's total energy consumption split by electric/diesel and passenger/freight activity. These total energy consumptions are combined with pkm and tkm data (allocated to diesel and electricity according to the repartition of passenger and freight train-km), allowing the calculation of energy intensities for passenger and freight activity where company data are available. Unfortunately the carbon content from railway inrastructure, i.e. building and maintance of railway infrastructure and construction vehicles/machines used for those purpose that usually emit significant amounts of carbon, is not included.

Currently, reporting companies use one of the IPCC based approaches to estimate emissions from their rail transport that are variations of the same fundamental equation:

$$E = F_C \times E_F \qquad (1)$$

Where:
E - emission,
F_C - fuel consumption,
E_F - emission factor.

The first approach, emissions estimated using fuel-specific default emission factors, assume that for each fuel type a single locomotive type consumes the total fuel. The second approach uses country-specific data on the carbon content of the fuel for different types of locomotives. The emission factors arrived at is to be specific to broad locomotive technology type. The third approach involves a more detailed modeling of the usage of each type of engine and train, which will affect emissions through dependence of emission factors on load. Data needed includes the fuel consumption which can be stratified according to typical journey and kilometers travelled by the train.

3. EMISSION FACTORS

For easier calculation infrastructure carbon footprint may be evaluated through four different phases: design, construction, operation and disposal. Planning railway construction is a shorter phase in terms of time compared to the life time of the infrastructure and mainly requires computers in engineering offices. Building railway tracks requires material production, transport and machines operating intensively for several years to adapt the topography to the rail line needs. All of these activites demands energy consumtion and consequetly carbon intensive emission. Maintenance requires machines and operation that usually emit significant amounts of carbon. Removing rail infrastructure tracks and all related material usually required machines powered by diesel producing significant amounts of carbon emissions.

Two existing standards have been adopted in the UICs proposed methodologies, ISO 14000 series, particularly ISO 14064 an GHG protocol a new standard that allow national approach for carbon content quantification.

Emission factors for each vehicle type may be determined via:

- CO_2 eq. Emissions / Passenger - km,
- CO_2 eq. Emissions / Ton – km.

Methodologies commonly used to determine Rail emission factors utilize the methodology using the following input data:

- Fuel consumed (diesel/electricity),
- Passenger km travelled,
- Freight transported (ton-km),
- National emission factors for fuel used.

Methodology for calculation using total fuel consumed by railway sector proposes arriving at rail transport emission factor when the overall energy consumption of the railway sector is available. It involves estimating the specific power/fuel consumption of rail transport (when no information on fuel split between passenger and freight trains is available but the total energy consumption by rail traction is known). This fuel consumption is then converted to emissions using the fuels' calorific value and emission factors. Emissions are then allocated to passenger and freight transport on a weighted average basis using distance performed as shown below:

$$\text{OVERALL EMISSIONS} = \left(D_c \times C_v \times D \times E_f\right) + \left(E_u \times N_{ef}\right) \quad (2)$$

Where:
D_c -total diesel consumed,
C_v - calorific value,
D - density,
E_f - emission factor,
E_u - electricity usage,
N_{ef} - national grid emission factor.

Emission factor CO_2 eq. emissionsper passenger and freight, could be estimated as follow:

$$\frac{\text{CO}_2\ \text{eq.Emissions}}{\text{Passenger}-\text{km}} = \frac{\text{Overall emissions}}{\text{passenger km performed}} \quad (3)$$

$$\frac{\text{CO}_2\ \text{eq.Emissions}}{\text{Ton}-\text{km}} = \frac{\text{Overall emissions}}{\text{freight ton}-\text{km performed}} \quad (4)$$

As black carbon always follow CO_2 emission, as a product of fuel consumption by diesel engines used in rail transport and in machinery for infrastructure building and maintaining that must have be under consideration in calculation of emission associated with fuel burned data.

The following equation can be used to calculate black carbon emissions with actual fuel burn data. Different fuel types should be calculated separately.

$$\text{Black carbon (g)} = \text{fuel (kg)} \times \text{black carbon em. factor} \left(\frac{\text{black carbon (g)}}{\text{fuel (kg)}}\right) \quad (5)$$

Black carbon is generally classified under the umbrella category of particulate matter (PM). In terms of air quality regulations, PMs are commonly divided by particle size: under 2.5 micrometers in diameter (PM2.5) and particles under 10 micrometers (PM10). For transport, 98% of PM emissions are within the category of PM2.5. PM2.5 emissions factors can be converted to black carbon using a PM2.5 speciation factor, as shown in Equation 6.

$$\text{Black carbon (g)} = \text{fuel (kg)} \times \left[\text{PM2.5 emissions factor} \left(\frac{\text{g BC}}{\text{g PM2.5}}\right) \times \text{PM2.5 speciation factor} \left(\frac{\text{PM2.5 (g)}}{\text{fuel (kg)}}\right)\right] \quad (6)$$

4. CONCLUSION

International Union of Railways (UIC) has published the “Carbon Footprint of High Speed Rail: Final Report” [11] presenting the results of a carbon footprint analysis. Earthwork, transport of construction materials, engineering structures, like bridges and tunnels, rolling stock manufacture, electrical and signaling equipment have been taken into account in the construction analysis. The total emissions from the construction of the high-speed rail are in the range of 58–156 $tCO_2\ km^{-1}$ of line $year^{-1}$. The results from the comparison of the road and rail transport systems highlight many interesting issues. However, the railway system operation is more environmentally friendly than the highway system operation.

Carbon footprint analysis would provide tools for sustainable development of infrastructure construction as well as deciding on alternate models of construction. The choice of materials and techniques in transport construction is dictated not only by structural requirements and economic aspects but also by environmental factors that have also gained in importance due to ecological considerations in politics.

The rail infrastructure is made up of a number of elements (track with ballast) including stations, tunnels, bridges, signaling and telecommunications. Including the carbon footprint of railway infrastructure in the eco calculations would reward those making an effort to mitigate carbon emissions over the construction, re-construction and re-building of the line by using more carbon friendly techniques. It would create a win-win situation, where the rail sector reinforces its sustainability lead, and where infrastructure and railway operators are further committed to reduce CO_2 emissions, and evaluating possible advantages of investments in railways as a solution to reduce carbon footprint in transport.

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CHARACTERIZATION OF BUTT WELD JOINT BY MIG WELDING PROCESS ON THE EXAMPLE OF ALUMINIUM ALLOY EN AW 6082

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Abstract *– The paper presents the test results of butt welded Al alloy joint EN AW 6082-T651 (t10mm). Filler wire was S-Al 5183. The purpose was to evaluate the achieved quality of the welded joint as a function of the applied technological parameters of the MIG welding process. Complying with all the standards, mechanical tensile tests (Rp0.2, Rm and A50), bending and hardness measurement HBW2.5 / 62.5 / 20 in base material (BM), heat affected zone (HAZ) and weld metal (WM) were performed. Macrostructural and microstructural analysis was performed on the cross section of the welded joint specimen after appropriate metallographic preparation. The results of microstructural analysis and mechanical tests showed that cracks and slag were present in WM. This can also be seen on fractured surfaces after tensile and bending tests. The presence of these defects significantly affected the weakening of the welded joint, more precisely the lower values of mechanical properties. It can be concluded that the applied technological parameters of the welding process do not provide a quality joint that meets the requirements of the standard.*

Keywords – welding, Al alloy, MIG, mechanical properties, macrostructure, wagon.

1. INTRODUCTION

It is known that the mechanical, physical and chemical properties of Al alloys depend on the chemical composition and the microstructure resulting from the applied thermomechanical processing [1, 2]. Thanks to a unique combination of properties such as precipitatioelectrical and thermal conductivity, low specific weight, strength, corrosion resistance, deformability, weldability and recyclability, Al and its alloys have become indispensable in the railway industry. This primarily applies to alloys series 5xxx (Al-Mg) and 6xxx (Al-Mg-Si). In the production of rail vehicles, these two series of alloys are widely used due to their good mechanical properties, good weldability and the ability to obtain large profiles by pressing, rolling or extrusion. Selected alloy 6082 T651 belongs to the group of medium strength alloys that can be regulated by precipitacion hardening and deformation [3]. Since in the field of rail vehicles this alloy is used for very responsible parts and load-bearing structures, obtained by welding, special attention is given to the control of welded joints that must meet strict quality criteria. Butt-welded joints of 10mm thick aluminum profiles are used, in the rail industry, most often for the construction of the wagon floor. Due to the load that this joint is subjected to, excellent mechanical and metallurgical characteristics are necessary, not only of the base material but also of the weld and heat affected zones.

Precisely, the purpose of this paper was to present a complete quality check of the welded joint of alloy 6082 T651 as a function of the parameters of the MIG welding process, in accordance with the requirements of existing standards [4].

2. TESTING PREPARATION

Experiment was done according to standard SRPS EN ISO 15614-2 Specification and qualification of welding procedures for metallic materials — Welding procedure test - Part 2: Arc welding of aluminium and

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its alloys.

2.1. Welding procedure specification

According to the preliminary welding procedure specification, the sample was welded with welding process 131 (MIG), type of joint and weld are BW, 10V. Base material is EN AW 6082-T651 with the thickness of 10mm, added material is S Al 5183 and welding position is PA.

2.2. Experiments done for qualification

For one qualification of BW aluminium joint to pass, all of the requirements made by the standard need to be checked. For the NDT Visual examination (ISO 17637), Penetrant test (EN 571-1), Radiographic test (ISO 17636) and for the DT: macrostructure and microstructure (ISO 17639), hardness test as an addition request (ISO 9015-1), tensile test (ISO 4136) and bend test (ISO 5173).

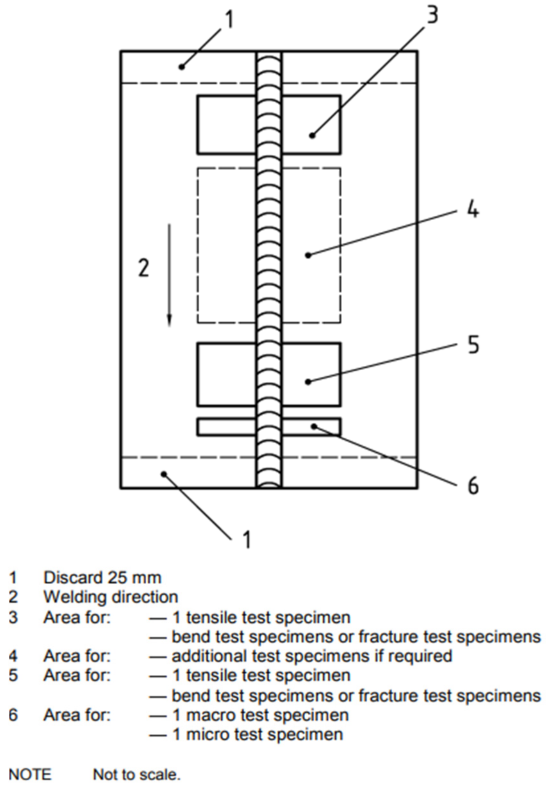


Fig. 1. Location of test specimens for a butt joint in plate [4]

2.3. Specimen preparation

Sample of the welded joint must be at least 300x300 mm from which the specimens are extracted. From each side 25mm is discarded because of the begining and the end of the weld is not tested. One specimen is neaded for each of the tests (microstructure, macrostructure and hardness), for tensile tests 2 specimens and for the bend test 4 specimens (*Fig. 1*).

Dimensions of the specimens and their preparations are chosen according to the relevant standards.

3. TESTING MACHINES AND CONDITIONS

Testing conditions for all the experiments done are chosen according to standards. Testing temperature was 23±5°C.

Machins that were used for testing were:

- Microscope Leica DM4 M
- Macroscope Struers StructureExpert Weld 5
- Universal testing machine Shimadzu AG-X plus 300kN
- Brinel hardness tester Echolab HTB 625Z

4. DESTRUCTIVE TESTING

Once all of the specimes were cut or milled out of the sample plate the testing could start.

4.1. Macrostructure examination

Specimen preparation was done on the machine for grinding and polishing Buehler Automet 300 and etched by 15% NaOH.

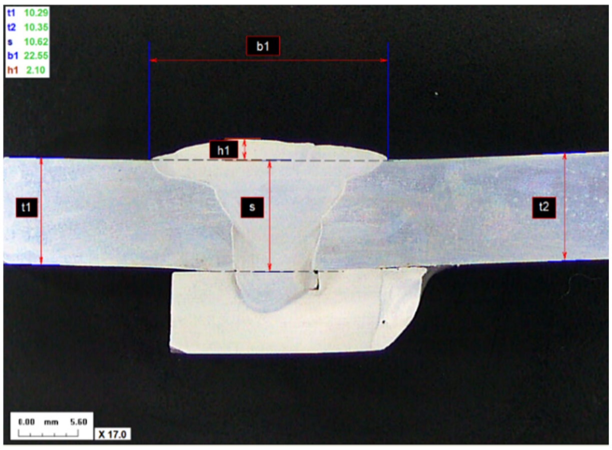


Fig. 2. Macrostructure

All the dimension that needed to be tested according to standard ISO 17639 for the quality level listed in SRPS EN ISO 15614-2 are good and there were no defects on the specimen.

4.2. Microstructural examination

Specimens was grinded, polished and etched and specific parts of the sample, where defects were noticed, were examined.

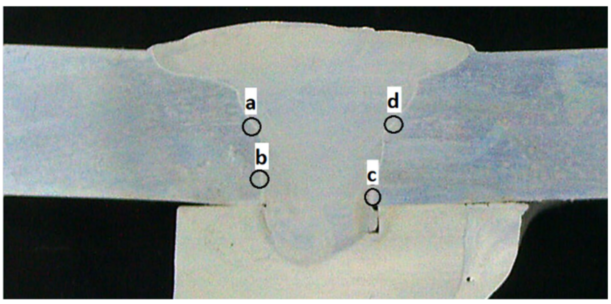
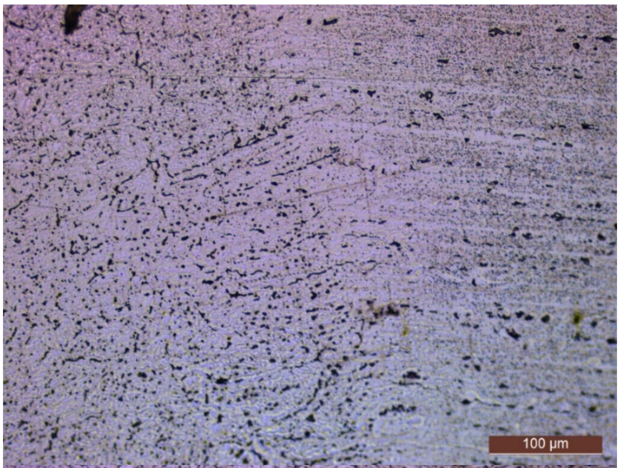
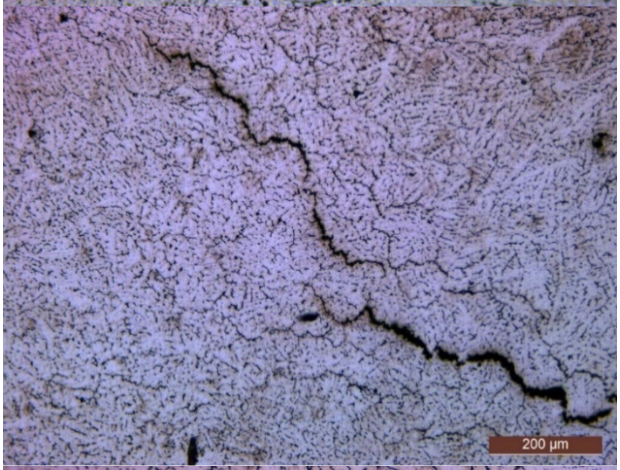


Fig. 3. Microstructure figure position

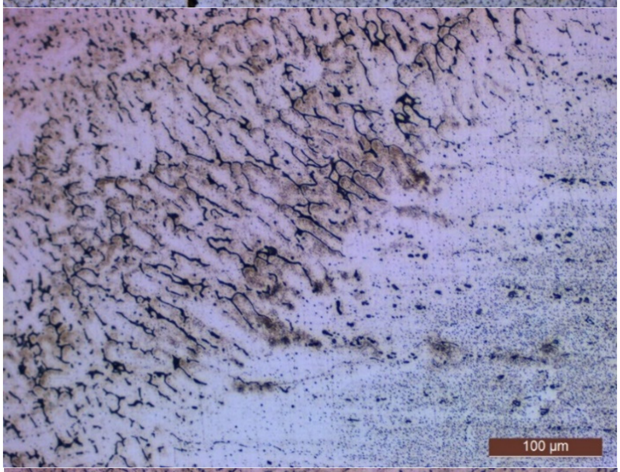
a)



b)



c)



d)

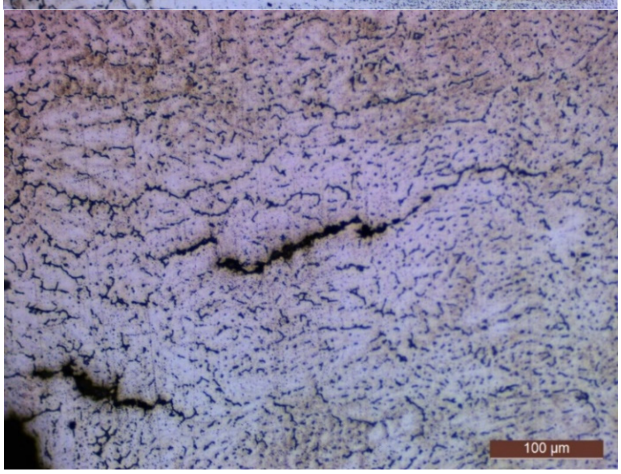


Fig. 4. Microstructure of the welded joint (positions corresponding to Fig. 3.)

Microstructure examination showed porosity in the narrow HAZ and zone of columnar structure in weld metal, Fig. 4. a, c. between weld and HAZ. Behind the columnar zone in WM cracks can be seen, most likely hot cracks and slag, Fig. 4. b, d. Fig. 4. a, d show that the fusion line stands out more than the HAZ.

4.3. Hardness testing

Hardness testing was done according to standard ISO 9015-1 for hardness testing of welded joints. This test showed no irregularities. Fig. 5 shows measurement places and Fig. 6. and 7. show diagrams of measured hardness and position.

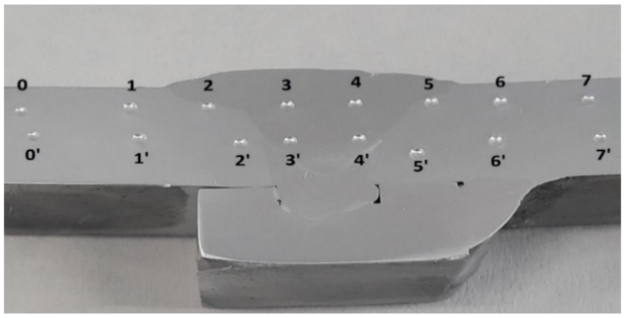


Fig. 5. Measurement places

Method used was 2.5/62.5/20 (2.5 mm ball, 62.5 kgF for the duration of 20s).

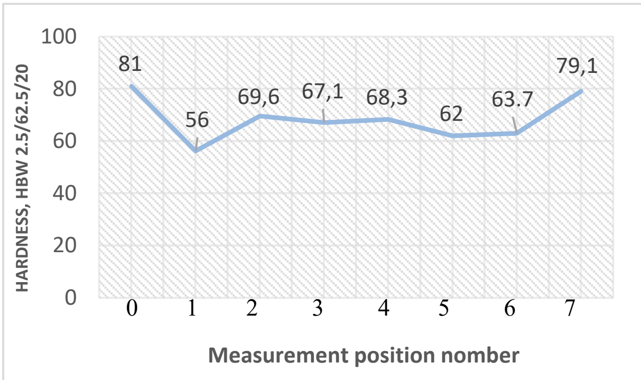


Fig. 6. Diagrams of measured hardness and position

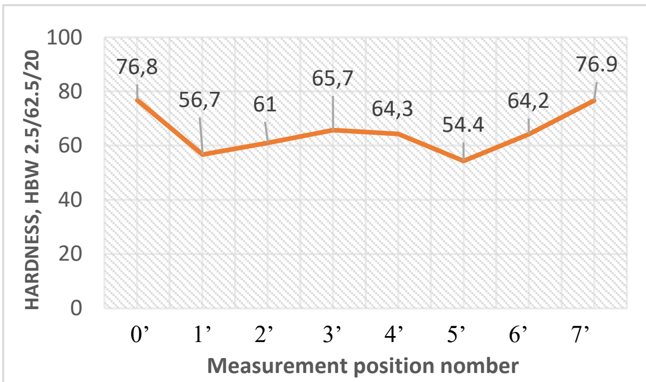


Fig. 7. Diagrams of measured hardness and position

4.4. Tensile testing

Tab. 1. Data colected from the tensile test

No.	Proof strength $R_{p0.2}$, MPa	Tensile strength R_m, MPa	Elongation after fracture A, %
1	134	218	7.16
2	138	217	8.17
Average value:	136	217.5	7.66

Tensile test was done according to standard (ISO 4136). This test showed the tensile characteristics of the welded joint, which has a lower limit on the tensile strenght.

According to standard EN ISO 15614-2 the tensile strength of the welded joint neads to be as strong as the tensile strength of the material multiplied by the joint efficiency factor T. (1)

$$Rm(w) = Rm\ (pm) \times T \qquad (1)$$

where

- Rm(w) is the tensile strength of the welded test specimen in the as post-welded condition;
- Rm (pm) is the specified minimum tensile strength of the parent material required in the relevant standard;
- T is the joint efficiency factor.

Factor T for EN AW 6082-T6 is 0.7 from which we can determine that the lower limit for Rm for this welded joint is 217 MPa which means the test juste barely passes. The stress-strain diagram for the first sample is shown in Fig.8.

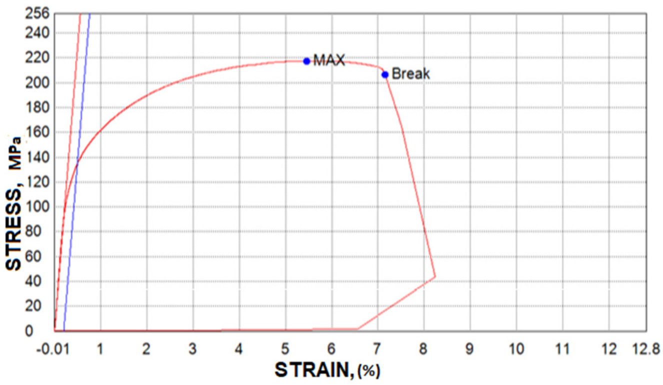


Fig. 8. Stress-strain diagram for the first sample

Break occurred in the heat affected zone which is shown in the Fig. 9. an the detal look of the broken surface can be seen in the Fig. 10.

4.5. Bend test

Bend test according to ISO 5173 was done. All the testing conditions were chosen according to this standard (distance between rollers, tool diameter, specimen dimensions, bend angle...)

Bend test was done on 4 specimens, 2 on the face side of the specimen (TFBB) and 2 on the root side of the weld (TRBB). Fig. 11. shows 1 specimen ater the bend test. All of the bent specims failed in the HAZ.

Fig. 9. Specimen failure site

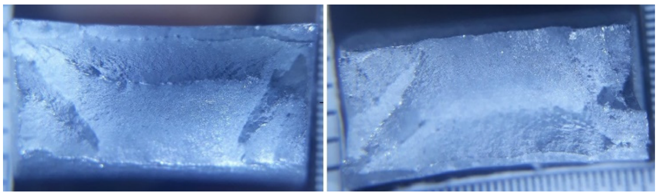


Fig. 10. Surface area of the specimen after tensile test

Fig. 11. Specimen after the bend test

5. CONCLUSION

All of the results, especially microstructure and bend test, show that these welding parameters were not adequate for this material. Microstructure showed presence of hot cracks and slag. Surface area of the breaking point after tensile test showed slag and porosity and bend test confirmed that the HAZ is to weak to pass the qualification. This welded joint would not withstand the forces on the floor of the wagon.

ACKNOWLEDGEMENT

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XIX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS RAILCON '20

HOT FORMING PROCESS OF UPPER PIVOT OF FREIGHT CARS

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Abstract *– The manufacturing technology of hot forging of the element of the upper pivot of freight cars is a good example of plastic deformation with a high degree of deformation. It is a process where from the preheated cylindrical steel workpiece, at a temperature of about 1100℃, a finished part, of complex and fragmented geometry, is obtained. Filling the farthest points of the upper and lower part of the tool is almost impossible without the application of special structural changes of the tool that will direct the plastic flow of steel.*

Keywords – hot forging, tool design, plastc flow, counterlock.

1. INTRODUCTION

Modern railways today require high quality infrastructure and equipment in order to achieve customer demands in terms of speed, comfort and reliability for the end user. In these conditions, the necessary equipment and elements of railway vehicles require the application of new or existing technologies that provide reliable solutions. Hot and cold forging processes are crucial technologies for the responsible elements of assemblies and subassemblies and such systems. Plastic flow in complex open forging tools is a very complex process because, as a rule, it is required to fill even the most distant parts of the volume of the complex finished part [1]. Large-scale and mass production involves making the work with a minimum number of strokes in order to obtain the final shape. If it is a very complex geometry of the finished part, it is sometimes not possible with the usual constructive solutions. Although there is a flash of surplus material with a transition bridge, as a guarantee that the filling of the tool cavity will be complete, with some tools this is not possible because it requires a very high degree of deformation in one direction or very small in the other [2]. The projected surplus material flows over the transition bridge and fills the flash of surplus material, but only after the farthest part of the tool volume is filled, which represents the inverse shape of the finished part. The large radius on the transition bridge towards the flash make it easier for the heated steel to flow out, and thus the farthest parts of the volume in the tool remain unfilled. On the other hand, small radius with a sharp transition make it difficult for the heated steel to flow out over the transition bridge, which directly causes damage and tool breakage.

The largest strains are localized in the central part, however, areas directly contacting tools are not deformed much, which is caused by presence of additional frictional resistance at the tool metal surface of contact. In the result, preform assumes a barrel shape. At the next stage – forging in initial impression – strains are considerably larger than in the previous case and their maximal values are localized in central area, near formed cavities. Preform is formed due to punching and upsetting with a small squeezing of material which gradually fills the impression in tools. The impression was designed in such a way that metal during forging does not touch tools walls in the plane area of their division. Because of that flash is not present and the formed preform can be directly transferred to the last die impression.

The small projected volume of the flash for excess material warehouse also causes permanent damage and even fractures of vital parts of the upper and lower tool [3]. All these requirements should be kept in mind when designing complex tools, but also with symmetrical and simple spatial shapes. But with complex, spatial geometric shapes, with different degrees of deformation, in different directions, that is not enough [4]. Therefore, solutions are applied in the form of constructive tool changes, which additionally

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direct the plastic flow towards the farthest parts to which the path of the heated material is traversed and the longest.

2. NUMERICAL MODELING

Experimental and production investigations were preceded by detailed analysis of numerical model of the analyzed forging process using QForm3D software. QFORM is based on so called flow formulation. The material is considered as incompressible, isotropic continuum and elastic deformations are neglected. In QFORM system initial FE mesh is generated automatically. Mesh density distribution is based on initial workpiece geometry and flow pattern [5].

To evaluate initial flow pattern several iterations are usually done with nearly zero time step at the eginning of the process. Remeshing procedure is also completely automatic and is based on current workpiece geometry, solution behaviour (strain-rate field) and tool geometry including the influence of the tool surface parts that are not in contact yet but can be touched by the metal soon. During simulation process finite element mesh is updated at each time step to follow the current configuration of the workpiece.

The system preference is given to direct iteration method having more uniform convergence characteristics. To reduce the number of iterations within the each time increment the solution obtained at the previous time step is used for the first iteration at the next time step. Due to small time increments the solutions at two subsequent steps are close to each other thus usually 3-5 iterations are necessary to achieve specified values of convergence criteria. Flow stress depends on strain, strain-rate and temperature. The heat generated by plastic deformation is also included into consideration (thermal coupling). QFORM software includes friction model proposed and experimentally verified by Levanov:

$$F_t = m\frac{\overline{\sigma}}{\sqrt{3}}\left(1 - e^{-1.25\sigma_n/\overline{\sigma}}\right) \tag{1}$$

where σ_n - normal contac stress, m - frictional shear factor, $\overline{\sigma}$ - yield stress of layer in workpiece near contact surface with tool. The workpiece was heated up to 1100 °C.

3. THE PROCESS OF HOT FORGING OF THE UPPER PIVOT

Due to the high degree of compression deformation, in the central part of the mold, a large amount of heated material is forced into the radial cavities of the tool. Such geometry of the finished part requires a distinct flow in four radial directions (Fig. 1) in order for the finished part to get a given functional shape.

At the beginning of the process, we have a short-term, free compression of the cylindrical preparation due to the action of the upper part of the tool until the filling of the hemispherical tool occurs. After the phase of free compression of the cylinder, we have the penetration of the upper part of the tool into the volume of the forging preparation and the formation

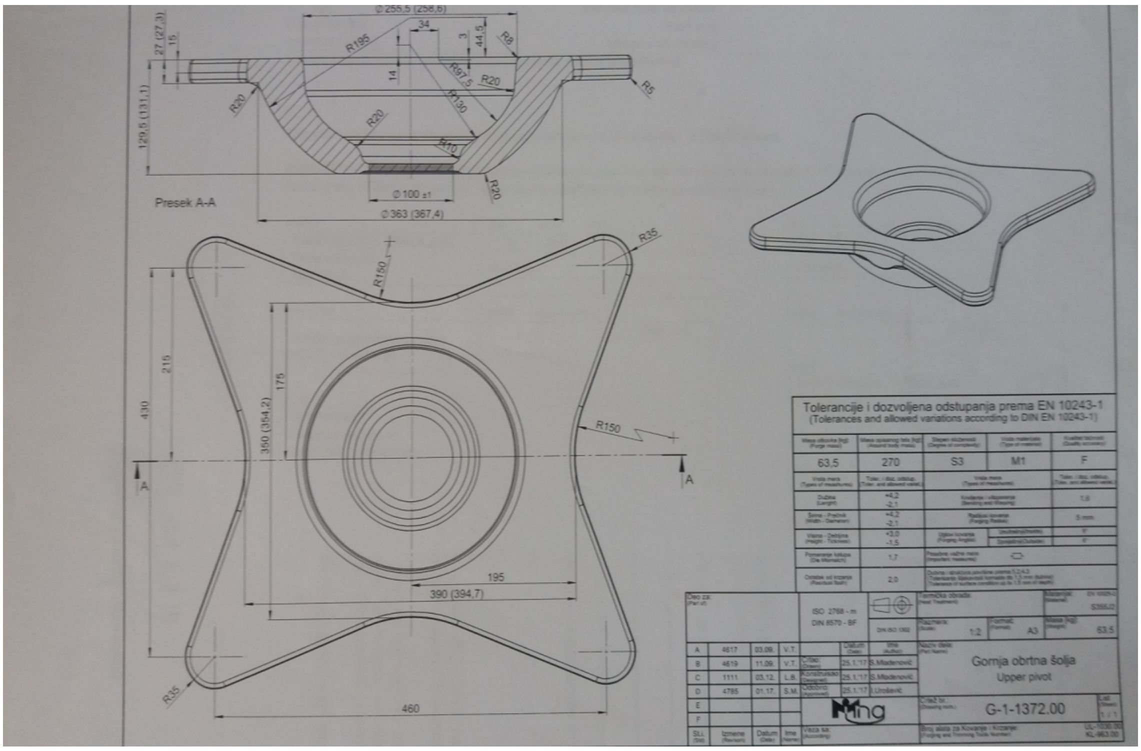


Fig.1. Geometry of the finished part of the upper pivot

of a dome of radius r130mm. The central volume of the tool is almost completely filled, thus forming a spherical part of the forging r195mm. The appearance of the part at this moment (Fig. 2) indicates the formation of the central part of the forging which is completed and passes to the filling of four, symmetrical, radially distributed tool volumes (Fig. 3).

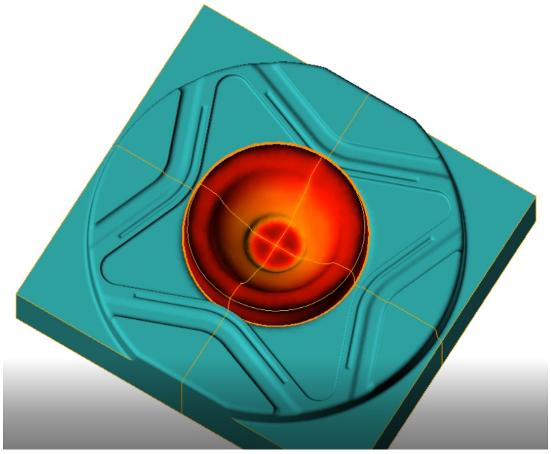
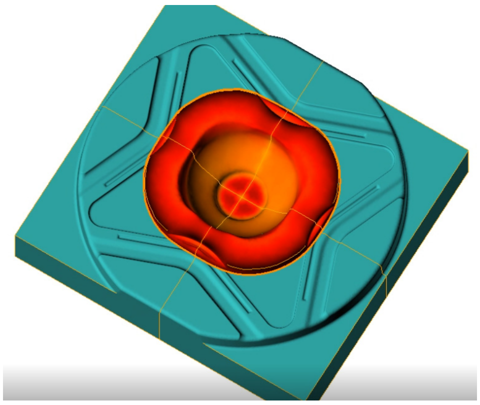
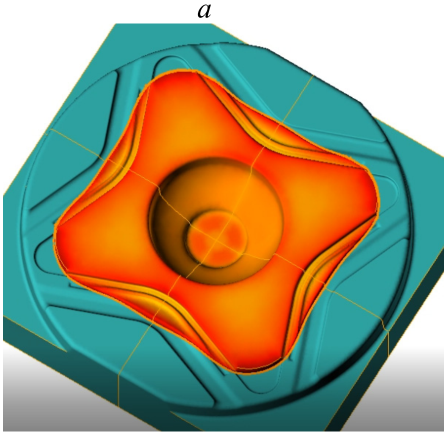


Fig.2. Free compaction of preparations with forging at the beginning of the process



a



b

Fig.3. Radial flow of material preparation and the beginning and end of the filling of the auxiliary channels

At the same time, in order to prevent the heated material from leaking out, in the remaining four radial directions (460 i 430 mm), it is necessary to apply mechanical obstacles in the tool that would prevent and direct the plastic flow. The simplest explanation for this effect is to increase the degree of deformation in certain flow directions so that the preparation material is directed in the desired direction at high temperatures. Namely, any sudden change in the geometry of the tool causes a delay in the plastic flow at such high pressures between the working surfaces of the tool. Specifically, in this tool we have a volume expansion in the form of channels that follow the contour of the part, in the upper or lower part of the tool (Fig. 3.), Which the heated material needs to fill thus creating greater resistance to plastic flow in the tool itself [5, 6].

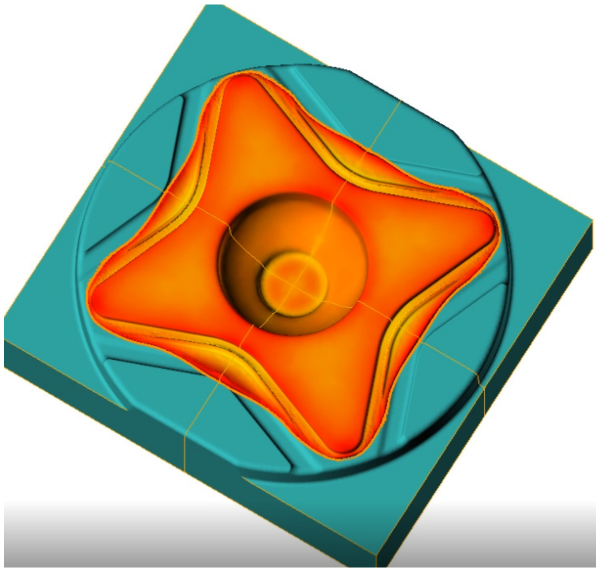


Fig.4. Filling the warehouse of surplus material in the final shape of forging

After the completion of the filling of the central part of the forging and the beginning of the filling of the radial volumes, the heated steel forging very quickly begins with the filling and auxiliary channels that will direct its movement to the most distant parts of the tool. At the same time, their filling prevents flow at a diameter of 350 mm (Fig. 3a), where most of the volume is deformed, or 390 mm (Fig. 3a), where the filling of the auxiliary channels has just begun. This prevents uncontrolled leakage and even tool filling. At the end of this phase, where the auxiliary channels are filled, the most distant parts of the volume remain at a distance of 430 mm and 460 mm, respectively, with a radius at the ends r35 mm (Fig. 3b).

This prevents uncontrolled radial protrusion of the material near the central part of the forging, but also its direction and plastic flow in radial directions of 27 mm height (Fig. 1).

The filling of the most distant parts of the tool volume is accompanied by the filling of the channels which represent the transition bridge with the excess material warehouse and whose filling guarantees that the farthest part of the forging volume is also filled (Fig. 4). The size of the bridge and its parameters such as the width and height of the transition bridge, the transition radius will define the amount and speed of material flow into that part of the tool cavity [7, 8]. Therefore, the speed of filling the most distant parts of the tool cavity will be defined, ie interventions and corrections on the tool, if necessary, are possible precisely through these parameters.

Due to the radial flow of a large amount of heated material and relatively small thickness between the upper and lower part of the tool (Fig. 5), there is an inevitable wavy effect on flat surfaces that causes geometric inaccuracies of forging but thus the finished part within its volume.

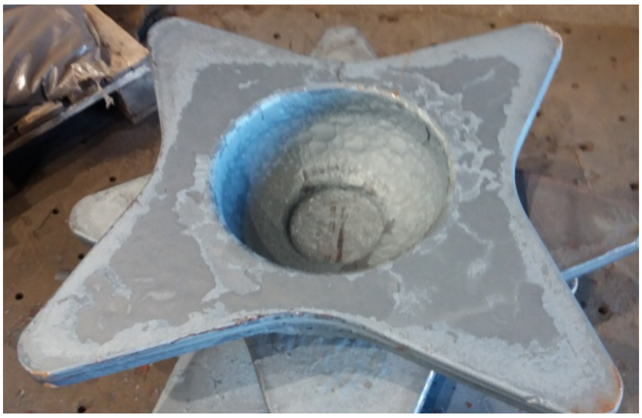


Fig. 5. Finished part with directions of geometric inaccuracies of forging in radial flow

Although well-worked tool surfaces, with relatively small irregularities (IT 5 grinding), on such a large distance traveled, from the largest preparation diameter (d = 300mm) to the most remote parts of the volume (d=730mm), cause large geometric dilatations that cannot be avoided in the forging process. Larger processing additives only increase the entire volume of the forging and the time required for their later removal. Additional processing is performed on machining centers by cutting procedures in order to obtain satisfactory geometric accuracy and parallelism of the surfaces of the finished element.

4. CONCLUSION

The advantages of the design process of such forging processes and the plastic flow inside the tool are reflected in the fastest possible technology, shorter forging process and less excess material that needs to be removed by post-processing. Sometimes this is not possible because the given shape of the finished part requires a rather complex process of plastic deformation in order to completely fill the mold cavity. For these reasons, software simulation is today an indispensable help in order to survive on the market with the lowest possible price with satisfactory quality and accuracy of forging.

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APPLICATION OF LASER TECHNOLOGY IN PRODUCTION AND MAINTENANCE OF RAILWAY VEHICLES

Marija VUKŠIĆ POPOVIĆ[1]
Sanja JEVTIĆ[2]

Abstract *– Although benefits of laser application in automotive industry have been proved they are not widely used in railway industry. Main reason is that batch sizes in the rail industry cannot cover high expense of lasers. An additional disadvantage is that railway vehicles have dimensions up to 25 m length so system for laser cutting and welding must be custom made. Application of laser technology in production and maintenance of railway vehicles can be for welding, cutting, hardening, cladding, etc. and non-contact measurement and condition monitoring of wheel flange or full wheel profile, axle parameters, etc. Examples of production railway vehicle parts using laser include welding large thin metal sheets for side walls and roof panels, cutting doors and windows openings on side walls, cladding wheels and buffer plates for wear and corrosion resistance, hardening of the railway vehicle pivots, etc. The laser devices for railway vehicles measurement are applied mainly for measuring geometrical parameters of wheel, axle and axle journal. The paper presents the possibilities of current laser technology in use and in development in the production and maintenance of railway vehicles, as well as the advantages of using lasers in relation to standard manufacturing and measuring methods.*

Keywords – railway, laser, production, maintenance, welding, cutting, hardening, cladding, measurement.

1. INTRODUCTION

Lasers have a proven fast, cheap and efficient performance in productions (for example in auto and shipbuilding industry). Regardless of lot of lasers benefits, they are not widely used in railway industry. Main reason is that batch sizes in the rail industry are at best several hundred parts and can't cover high expences of purchase and installation of lasers. Since railway vehicles have dimensions up to 25 m length adequate system must be developed for laser cutting and welding. Also the designe and safety standards in rail vehicle manufacturing can be higher than those in the auto industry [6].

Railway vehicles have a service life of at least 30 years, and therefor have developed extensive and complex maintenance system and technology. Since railway vehicles have such long live cycle, and tare weight contributes to increased fuel consumption, manufacturers are trying to reduce the weight of rolling stock. Lasers have been used in the production of side walls, roof panels and undercarriage components. Vast number of railway vehicles' parts are with small thicknes and openings on them could be created using lasers.

For example, substantial application of laser was production of around 1,600 rail cars for ICE 4, which Siemens/Bombardier have built for Deutsche Bahn. The bodies of light railway vehicles were made of aluminum to be lighter, but aluminum generally has a lower tensile strength than steel. So use of aluminum require thicker materials and larger profiles. To provide strength and stay within the weight limits, steel side walls, roof panels and outer shells usually cannot be thicker than 2 mm. Welding thin metal sheets by conventional means, with high amount of heat would make the walls distorted [6]. Lasers welding can provide high quality of weld seams, even thin sheets can be without distortion and don't need any additional work.

Lasers can also be used for profile scanning for railway condition monitoring application to capture the profile of railway vehicles wheel profile.

Application of laser technology in railway industry and maintenance can be devided:

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- For production of railway vehicles (welding, cutting, hardening, and cladding),
- For non-contact measurement and condition monitoring of rail profile, rail cross section, wheel profile, etc in maintenance.

2. LASER APPLICATION FOR PRODUCTION AND MAINTENANCE

Examples of production and maintenance railway vehicle parts obtained using laser include:

- welding large thin metal sheets for side walls, roof panels, thin outer shells and undercarriage components
- cutting large metal sheets and cutting doors and windows openings and ventilation openings,
- cladding on wear and damage wheels, buffer plates etc. for wear and corrosion resistance,
- hardening etc.

2.1. Laser welding

With the use of a lens, laser light can be directed and concentrated at the point of the material cousing desired effect. In that manner laser welding fuse and join surfaces together. Heat is transfered deeper below the surface, to enable depper and more narrow welding.

Various joints could be welded using lasers and its contactless processing is usually single-sided, not requiring filler material during welding. Highly concentrated beams allow high speed and automation. Laser welds can be classified by the medium they use. The most common variations that are used for welding metal are the YAG laser and the CO_2 laser. The main elements of a laser welding system are a laser oscilator, transporting medium, the condenser, the driving platform, and the assisting gas (Fig. 1).

From the laser itself the beam is directed by mirrors and lenses to the condenser. It is then projected into a small area on the material surface through the condenser. The parts are moved on the platform to be welded together [8]. The platform can be adjusted to fit any welding direction that is required.

Conventional methods use high heat for welding and as a result of heating residual stress occur and lead to deformation of material. Laser welding have high welding speed and concentrated energy. After laser welding there are no additional process such as grinding welds, cleaning the rest of the weld (cracks) etc. For thicker materials welding is made using the "Key hole" method.

Application of laser welding in railway industry and maintetnance are used:

- to replace resistance spot welding process for stiffeners assembly on railway vehicle side panels [2],
- for weight savings of welding stainless steel roof panel (up to 15% [7] for a commuter train),
- for high weight savings by welding sheets of different thicknesses, grades, etc. of side walls, panels, outer shells, etc.
- reinforcements by using thicker material to withstand the higher loads, such as in the window corner,
- for 3D structural assembly side wall for a high-speed train made out of horizontal and vertical stiffeners that are laser-welded to each other and to the outer panel [7] etc.

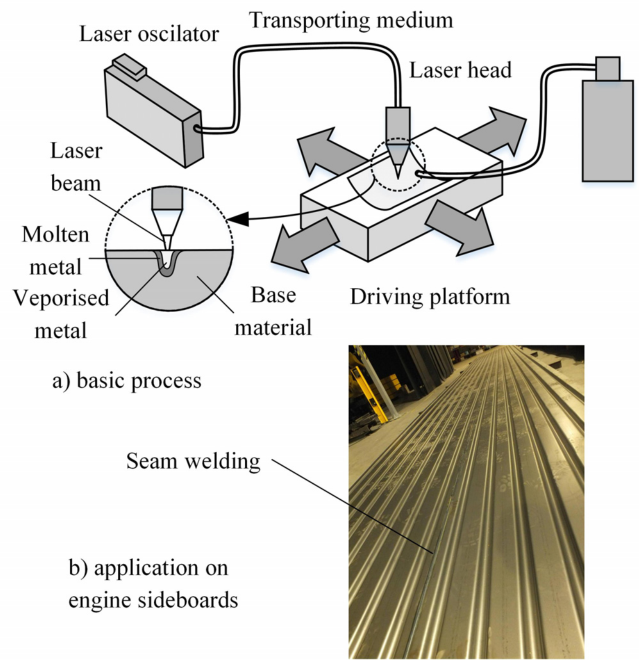

Fig.1. Laser welding [5]

Advantages of laser welding over spot welding are:

- water tight without additional insulation (spot welding leaves open areas between the welded spots),
- more resistant to stress and deformation compared to the spot welding (laser welding generates enhanced strength and rigidity as a result of the constant welded area without gaps),
- heat is rapidly applied in a small area along the edges to be joined, thus creating very little distortion in the welded area,
- not require heavy clamping devices so there are no bends or scratches on the panels resulting in smooth and appealing finish of the body.

The laser welding and the inspection of the welds must be done according to standards ISO 15614-11 and ISO 13919-1. The European standard EN 15085-2 defines the levels of certification (CL1 – CL3) depending on the safety relevance of the welded railway components.

For welding the materials with the thickness range above 5 mm, hybrid laser welding (coupling a laser beam with an GMA - Gas Metal Arc welding arc) can be used. Coupling the laser radiation beam with the welding arc rise welding heat. While welding a T-joint with hybrid laser it can be obtain complete penetration without the necessity of bevelling sheet edges, at a rate of 40-60 cm/min. Thickness of sheets with one-sided access is approximately 10 mm, where the welding rate is limited by the fillet weld thickness and not by laser power. [3]

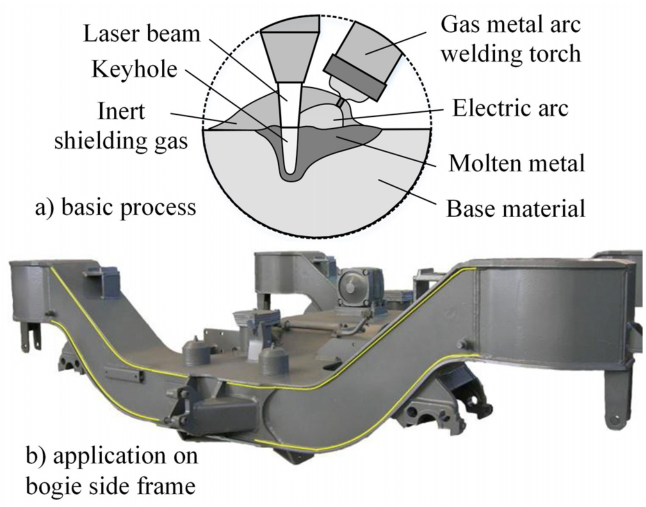

Fig.2. Hybrid laser welding [1]

2.2. Laser cutting

Laser cutting give a possibility of cutting holes and teeth on the parts that would be used for positioning during assembly and welding. This reduces the need for complex welding positioning tools. Laser cutting machines can facilitate and speed up production, reduce logistical work and improve the quality of the parts. After laser cutting, it is usually not necessary to subsequently process the holes or contours due to the quality of the cutting. Holes can be cut in a narrow field (± 0.2 mm).

Fig.3. 2D Laser cutting on the openings in a railway vehicle's side wall [8]

2.3. Laser hardening

Laser hardening is process of heating the workpiece quickly with a focused laser beam (while keeping the temperature above hardening level during the dwell time) and cooling by self-quenching. The heating temperature and time flow is specific, so distortion can be avoided, additional work is eliminated and without cooling media heat conduction dissipate into the base material.

Laser surface hardening has a lot of advantages over others such as low distortion due to high power density, flexibility, accuracy, lack of quenching medium and limited grain growth. For example, laser hardening of the railway vehicle pivots (Fig. 4.a) from material 42CrMo4, with depth of hardening 1,5 mm and surface hardness 55 HRc is obtained with laser type LDF 6000-40 (6,2 kW) [5].

2.4. Laser cladding

Sometimes, railway wheels cannot be repaired and have to be discarded far before its time in service due to local defects and severe wear. Laser cladding deposit of a wheel tread surface layer (Fig. 4.b) can repair wheels locally and prolong wear life of wheel. There were studies with different cladding materials that were deposited at defect sections of wheel surfaces. As cladding materials were used 316L, 410, and 420 stainless steel. Test results indicate that cladding didn't effect adhesion coefficients and wear rates of wheel, but cracks occurred between clad and unclad zones probably caused by shear stress due to the difference in deformation between clad and unclad materials. [4]

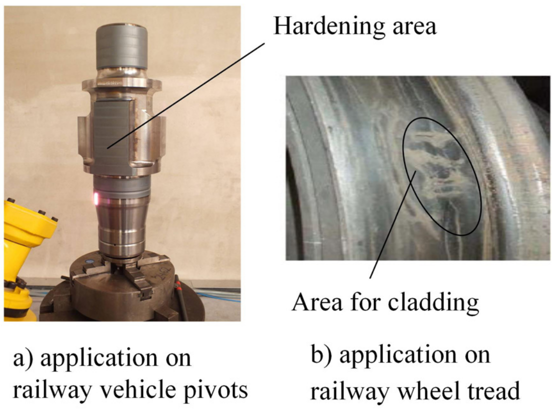

Fig.4. Laser hardening [5] and cladding

3. LASER APPLICATION FOR MEASUREMENT

The laser devices for railway vehicles measurement are applied mainly for measuring geometrical parameters of wheel, axle and axle journal, like wheel profile gauge, wheel diameter, back-to-back distance between railway wheels, disk brakes profile gauge etc [9]. The most common is profilometer for measuring geometrical parameters (Fig. 5.b) of the wheel flange (thickness, slope, height), rim/tire thickness or for taking full profile measurement of the wheel roll surface. The measuring devices are usually supplied with a database and software package for data storage and processing. Wheel profile gauge can measure geometrical parameters of the railway wheel flange with measurement error ± 0,05 mm and flange slope ± 0,1mm (tolerance depending on the manufacturor). Also, there are various automated wheel sets control systems (Fig. 5.a) that uses lasers to illuminate the inner and outer side of wheel, while high-resolution inner and outer camera records an image of the wheel. These systems can automaticly measure over 20 geometric parameters of wheel pairs in inspections carried out in railcar/wheel shops, wagon depots and workshops.

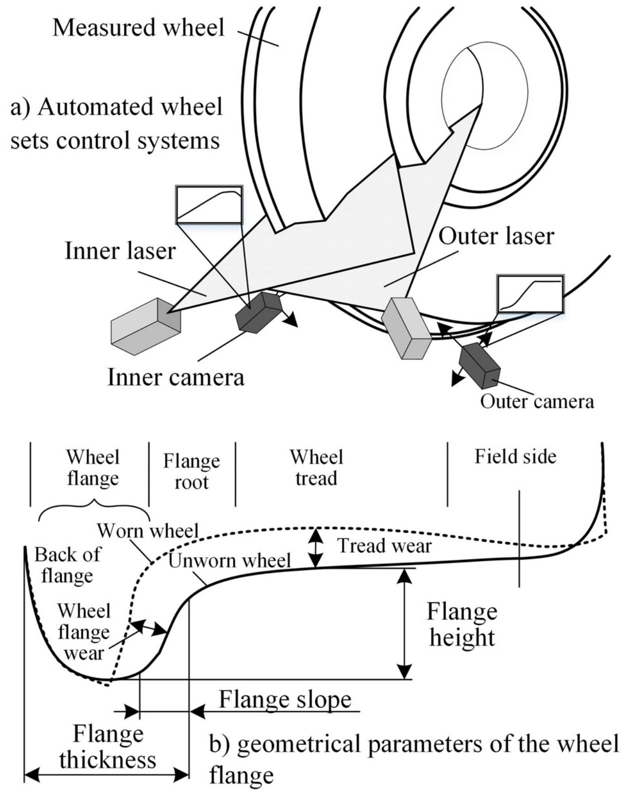

Fig.5. Laser measurement system for railway wheel

Conventional inspection methods are based on visual inspections and measurement with various, mainly, mechanical manual measuring instruments that are in comparison with laser scanning slower, less accurate and efficient. Laser scanning devices that require precision and accuracy at micrometer scale (usually three-dimensional laser) can be slower and have problems with reflection of shiny metallic or corroded parts. The laser scanner main advantages are:

- Faster and more accurate measurement, improved by using two or more laser scanners (and capture the entire wheel tread and body), that saves time and costs,
- Continually comparation of ideal profile with the measured profile,
- Higher accuracy than the previous subjective visual inspection or mechanical manual measuring,
- Fast transfer of measurement data.

4. CONCLUSION

The paper presents the possibilities of using laser technology in the production and maintenance of railway vehicle parts, as well as the advantages of using lasers in relation to standard methods. The laser is already used for the production of sides, roof, lower plinth and longitudinal girders in the production of railway vehicles in Bombardier, Tver Transmashholding, Göcke and on the Indian railways. The application of lasers requires entire plants that provide automatic handling and cutting or welding, since elements of supporting structure are large in height up to 3 m and length up to 26 m. This is, beside high cost of laser tehnology, the main disadvantage of laser application, as the construction of such plant requires a large initial investment and is economically justified only with large number of railway vehicles. Also software and equipment must be integrated including system for measuring, monitoring and adjusting parts geometry. Laser based geometry measurement systems for railway vehicles are contactless, smaller, faster and more accurate than mechanical devices.

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XIX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS RAILCON '20

USAGE OF ÖBB ELECTRIC LOCOMOTIVES ON THE CROATIAN RAILWAY NETWORK

Milan BRKIĆ[1]
Dragan MILJANOVIĆ[2]

Abstract *–The railway market in Croatia was opened for freight transport on 1st of July 2013. After that, several railway undertakings received licenses and safety certificates for railway operations in Croatia. One of them was Rail Cargo Carrier-Croatia (RCC HR) as a daughter company of Rail Cargo Group (RCG), member of ÖBB Holding. After getting safety certificates RCC HR as operator started production activities in 2015 using electric locomotives series ÖBB 1063. Further development of production of RCC HR resulted with implementation of several types of ÖBB locomotives. Today, RCC HR is capable to use more types of ÖBB electric locomotives with additional approval for Croatian railway infrastructure. Because of specific infrastructural conditions in Croatia, the company RCC HR had to develop own traction models for using ÖBB electric locomotives.*

Keywords – railway market, railway undertaking, traction model, certificate, railway infrastructure

1. INTRODUCTION

Republic of Croatia has opened railway market for freight traffic on 1st of July 2013. After that, several companies in Croatia were registered as a Railway undertaking (RU). One of RU's became daughter company of Rail Cargo Group member of ÖBB Holding from Vienna. This RU has an official name Rail Cargo Carrier-Croatia d.o.o. (RCC). The first activities of RCC as a new RU was preparing documentation for getting safety certificates and approvals for locomotives from ÖBB fleet. Because of the condition of railway network in Croatia, it was decided to request approvals for several types of locomotives for usage in Croatia. Because these locomotives were built earlier, they belonged to non-TSI compliant vehicles.

2. OBTAINING OF APPROVALS FOR ÖBB LOCOMOTIVES FOR CROATIAN NETWORK

According to, at that time, valid Law on the Safety and Interoperability of the Railway System in Republic of Croatia, the application for the issuance of a permit for the commissioning of a railway vehicle (homologation) was submitted to the Railway Safety Agency. The authorization procedure for issuing approvals started in 2014 for 3 series of electric locomotives which belong to ÖBB fleet: 1063, 1116 and 1216 and one type of diesel electric locomotive ÖBB series 2016. In the year 2019. approvals in Croatia have been issued also for locomotives ÖBB 1293 (Vectron) full built related to TSI LOC&PASS.

3. PRODUCTION AREA OF ÖBB LOCOMOTIVES AND THEIR PERFORMANCES

The most important railway lines in Croatia are: Border with HU - Koprivnica - Zagreb – Rijeka and Border with SI -Zagreb - Dugo Selo - Vinkovci – border with SRB.

Both main directions are electrified with 25 kV, 50 Hz system. With the same system are electrified lines Rijeka – Šapjane – border with SI, Zagreb – Sisak – Volinja – border with BIH, Sisak – Novska, Strizivojna Vrpolje – Slavonski Šamac – BIH, border with BI – Metković – Ploče and branch lines Škrljevo – Bakar and Sušak Pećine – Rijeka Brajdica. The heaviest sections are Moravice – Rijeka - Šapjane and Škrljevo -Bakar (inclination up to 26‰).

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Fig. 1. Croatian railway network (category of lines)

3.1. Electric locomotives ÖBB series 1063

At the beginning of production in Croatia RCC used only locomotives ÖBB series 1063. In fact, this AC locomotive is electric shunting locomotive with power of only 1,6 MW. Because several of these locomotives were available, it was possible to take them to Croatia and in 2015 to start hauling transit trains between Hungary and Slovenia via Koprivnica and Zagreb. Usage of this locomotives was limited on trains up to 1.600 gross tons on lines with inclination up to 10‰.

Main characteristics of 1063 locomotive [1],

- -Power 1,6 MW
- -Starting traction force 260 kN
- -Continuous traction force 68 kN at 80 km/h
- -ED brake force 120 kN
- -Weight 82 t
- -Axle arrangement Bo'Bo'

Fig 2. Locomotive ÖBB series 1063

After later implementation of Taurus locomotives 1116/126 these low power locomotives became only back up locomotives for light trains or could be used as additional front locomotive at heavier trains or as pushing locomotive.

3.2. Electric locomotives ÖBB series 1116/1216

Locomotives ÖBB series 1116 and 1216 are universal electric locomotives produced by Siemens and belong to platform Taurus. Locomotive 1116 is AC locomotive for power supply system 15 kV 16 ⅔ Hz and 25 kV 50 Hz [2]. The 1216 is a multi-system locomotive which can operate on both AC systems and 3 KV DC [3]. In Croatia they are used on the power supply system 25 kV 50 Hz. These locomotives are used mostly as single train locomotives but also as additional front locomotive and intermediate locomotive. Locomotives 1216 can be used as interoperable in cross border traffic between Slovenia and Croatia. Because of the similar performance as 1116, these 2 types can be treated as the same type.

Fig 3. Locomotive ÖBB series 1116 (Taurus)

Main characteristics of 1116 locomotives:

-Traction power 6,4 MW
-Continuous traction force 250 kN at 92 km/h
-Max. reg. brake force 150 kN (240 kN)
-Max. speed 230 km/h
-Weight 86 t
-Axle arrangement Bo'Bo'

Locomotives 1116 and 1216 could be used in tandem in all combinations so one train driver in his cabin can manage 2 locomotives at the same time.

3.3. Electric locomotives ÖBB series 1293 (Vectron)

The locomotive ÖBB series 1293 is a quite new series of locomotive and it is a universal, multi-system locomotive capable on electrified power supply system 3 kV DC, 15 kV 16 ⅔ Hz and 25 kV 50 Hz. In total, 47 locomotives of this series could be used on the Croatian network. Because of improved control system this locomotive has higher traction performances in comparison with locomotives 1116/1216. Locomotive 1293 could be used in tandem with 116 and 1216 locomotives.

Fig 4. Locomotive ÖBB series 1293 (Vectron)

4. CONDITIONS FOR TRACTION

Usage of locomotives depends on traction performances and track conditions. Because of various conditions in Croatian railway infrastructure, usage of locomotives should be optimized.

4.1. Railway line Gyékényes-Zagreb-Dobova

This section is an important transit line in Croatia, stretching between Hungary and Slovenia including 2 border stations, Gyékényes in Hungary and Dobova in Slovenia. Inclination of direction from Hungary to Slovenia is max. 6‰ and in opposite direction it is max. 8‰. There are no important limits regarding the train weight for single locomotive. Locomotives 1116/1216/1293 can haul trains up to 2.500 gross tons from Hungary to Slovenia, and trains up to 2.200 gross tons from Slovenia to Hungary. Train length is limited up to 550 m. On this line, maximum speed of freight trains is 100 km/h. On this line, low power locomotive 1063 can be used for hauling trains up to 1.600 gross tons but with reduced speed up to 70 km/h.

4.2. Railway line Šid –Zagreb- Dobova

Transit line in Croatia, between Serbia and Slovenia, include 2 border stations, Šid in Serbia and Dobova in Slovenia. Dobova is also a station with the surface between 25 kV AC system and 3kV DC system. Inclination in both directions is max. 6‰. Locomotives 1116/1216/1293 can haul trains up to 2.500 gross tons in both directions as a single locomotive.

4.3. Railway line Zagreb-Rijeka

This line represents a connection between Port of Rijeka and refinery Šoići. Mountain section Moravice – Rijeka is the most demanding line in Croatia because of inclination up to 26 ‰.

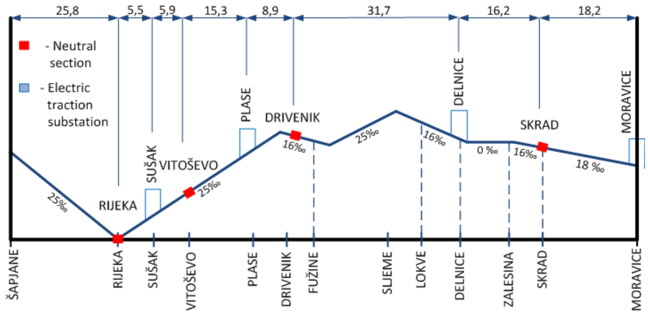

Fig. 5 The section Moravice – Rijeka - Šapjane

4.3.1. The main characteristic of the line relevant to Traction

a)*Inclinatian/resistance*
Fig 2. Locomotive ÖBB series 1116 (Taurus)
Moravice – Drivenik 18‰/22 daN/t
Rijeka – Šapjane 25‰/27 daN/t
Rijeka – Lokve 26‰/29 daN/t

b)*Hauling hook limit [4]:*
Moravice – Drivenik 1551 t
Rijeka – Šapjane 1288 t
Rijeka – Lokve 1206 t

c) *Traction with single locomotive 1063/1116/1293 with continuous 40 km/h on the max. incliniation part*:
Moravice – Drivenik 470 t/930 t/1050 t
Rijeka – Šapjane 360 t/760 t/860 t
Rijeka – Lokve 330 t/800 t

5. IMPLEMENTED TRACTION MODELS ON THE LINE ZAGREB -RIJEKA

Optimal traction model shows how to use available resources with minimal costs. Usually a small RU does not have big resources (locomotives, staff) so each traction task must be carefully planned. On Zagreb - Rijeka line RCC performs heavy and light trains in both directions. Because of inclination up to 8‰ (railway resistance up to 10 daN/t) Zagreb-Moravice part is not demanding.

5.1. Actual traction models

Planned max. mass of train from Hungarian border to Rijeka, according to the actual timetable is 1900 gross tons. Such train can be hauled with a single locomotive 1116/1216/1293 till Moravice. On the section Moravice-Rijeka such train should be split in 2 parts or hauled in one piece with additional locomotive inside the train, if it is available. Adding a locomotive is usually available if the traffic is intensive. If not, train must be forwarded to Rijeka in 2 parts with weight suitable for a single locomotive (1116/1216 - 950 t, 1293-1050 t).

Planned max. mass of train from Rijeka to Lokve, according to actual timetable is 1206t for 2 x 1116 locomotives. In the station Lokve, 2 trains could be set in one train suitable for single locomotive 1116/1216/1293. If only one locomotive is available train will drive with reduced mass, and in Lokve such 3 light trains could be set in one heavy train towards Zagreb and Hungarian border.

5.2. Further improvement of traction models

With the engagement of stronger locomotives, such as adding the pushing locomotive in Moravice, RCC wants to increase train performance on this line.

Traction force of pushing locomotive is limited to 150 kN but it could be increased to 240 kN.

With 3 locomotives, mass of train from Moravice to Rijeka could be 2.500 gross tons.

In opposite direction, till Lokve, heavy trains up to 2.000 gross tons can be hauled with 2 head locomotives (1116/1216/1293 +1063) and one middle locomotive (1116/1216/1293) because of hook limitation.

Fig.6. Traction with 3 locomotives on the section Rijeka – Lokve

During such traction, the total traction force of the locomotive at the front must not exceed 450 kN, and the pushing force of the intermediate locomotive must not exceed 150 kN.

Trains with loaded containers usually are lighter but longer (up to 1.200 gross tons, 500 m). Traction model for these trains on the section Rijeka – Lokve should be one locomotive 1116/1216/1293 plus 1063 or a tandem of 1116/1216/1293.

6. CONCLUSION

RCC, as a member of ÖBB and RU in Croatia had to implement several types of locomotives from ÖBB fleet. Because of various conditions at railway infrastructure RCC had to develop own traction models with ÖBB locomotives for hauling freight trains. For the most demanding railway line to Rijeka RCC had to find the most optimal solution using multiple traction with electric locomotives series 1116, 1216 and 1293.

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The Graduates and the Future of Railway

MAAS IN EU RESEARCH PROJECTS FOR A BETTER POSITION OF RAILWAYS IN PROVIDING TRANSPORT SERVICES

Student: Teodora MILENKOVIĆ[1]
Mentor: Branislav BOŠKOVIĆ[2]

Abstract *– Although mobility basically represents the mobility of people and goods in an area, mobility as a service implies a so-called transport service that satisfied all the requirements of the users regarding the quality of the transport service provided to them. The aim of this concept is to reduce the use of individual vehicles and equally share participation in the transport process between all modes of transport. It is precisely the chance of railway to increase its share in the transport market. This paper will describe the concept of MaaS through the presentation of research and projects supported by EU funds, as well as the potential chances for participation of the railway in it. Finally, an analysis of all the effects of the introduction of this concept will be given, as well as conclusions how much this concept is useful in a particular territory.*

Keywords - MaaS, mobility, railway, EU funds

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XIX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS RAILCON '20

PERFORMANCES AND INDICATORS OF THE RAILWAY SISTEM OF THE SERBIA IN THE TRANSPORT OF GOODS

Student: Marija SELAKOVIĆ[1]
Mentor: Branislav BOŠKOVIĆ[2]

***Abstract** – Railway performance indicators provides an input for decision-making process in railway system management. Due to complexity of the railway system, the chosen indicators should help decision-makers to get answers to questions as such as what the characteristics of the network are, how the network works and how it is used in a given period, taking into account the data availability and method of their collection. Therefore, the right choice of performance indicators and the method of their calculation is very important to decision-makers in the successful management of the railway system. The right choice of indicators is especially important in changing conditions induced by implemented structural reforms of the railway system, which is now on-going process in Serbia. In different environment, it is necessary to reconsider current freight performance indicators and whether they affects on the decision-making process. Therefore, the first part of thesis gives an overview of the existing indicators and their analysis. The second part of thesis propose new indicatiors which are more market oriented and they are inspired with indicators used on railways in Australia. All proposed indicators are classified into three catogories: the train efficiency indicators, quality of the infrastructure indicators and railway market indicators. Finally, based on the available data, the values of the new proposed railway system indicators were calculated.*

Keywords – railway system, transport of goods, performance, indicators, market competitiveness.

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DETERMINATION OF BOTTLE-NECKS FOR THE BEOGRAD CENTAR-NOVI SAD-SUBOTICA RAILWAY THAT LED TO MODERNIZATION DEMAND

Student: Milan JOVETIĆ[1]
Mentor: Predrag JOVANOVIĆ[2]

Abstract – *The railway line Belgrade Center - Novi Sad – Subotica is of great strategic significance, it connects 3 out of 5 biggest cities in Republic of Serbia, but it also represents a part of Paneuropean corridor X b and it's also a core part of European railway network (TEN-T). In this paper, the capacities of Belgrade Center - Novi Sad railway were determined. They were determined, by use of classic method for line capacity calculation, UIC method for line capacity calculation from the year 1979 (UIC 405-1) and the newest modification of UIC method, from 2013. (UIC 406) as well. Considering the results from the calculations and considering the results from the scientific work (Mandic, Todorovic 2009) bottle-necks for the Belgrade Center - Novi Sad – Subotica railway were defined.With the calculation of the line capacity between Beograd Centar and Novi Sad it was determinaded that the bottle neck between Stara Pazova and Indjija.Observing the whole section between Beograd Centar and Subotica, it was determined that the bottle neck between Backa Topola and Zednik.*

Keywords - capacity, line capacity, capacity utilization, bottle-necks, railway

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KAKO OCENITI RIZIK U TRANSPORTU OPASNE ROBE

Student: Stefan SREDOJEVIĆ[1]
Mentor: Branislav BOŠKOVIĆ[2]

Abstract *– Civilizational pursuit of social progress is conditional on technological developments. Modern technological innovations require that dangerous goods make up a significant share of production and transport capacities. With the introduction of new technologies, the need for additional resources is growing, which is reflected in the increase in the transport of dangerous good. Therefore, there is a need for risk assessment in the transport of dangerous goods.*
The diploma thesis describes how to perform a harmonized risk assessment in the transport of dangerous goods and provides a general description of the harmonized method of risk assessment and all the necessary information to describe the risk situation being assessed. To describe each risk situation, information is used relating to the description of the transport infrastructure and the transport operation in which the transport infrastructure is considered, the description of the transport of dangerous goods, then the description of critical points and the description of hazards and reference scenarios for dangerous goods. Established a complete multimodal approach to the description given situation risk management is explained how that is done every step of the risk assessment as accurate as possible, taking into account the state of the art techniques, the restrictions relating to the availability of relevant data and goals in connection with the case of decision-making.
Through the examples of the Naftna industrija Srbije, the way of risk assessment and management in the company is shown. Dat is a register of identified HSE risks related to the exploitation of railway transport means and associated railway equipment and a proposal to prevent the fall of workers handling the loading racks.

Keywords – dangerous goods, risk, transport, European Union Agency for Railways.

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TECHNOLOGY AND PERFORMANCE INDICATORS OF NATIONAL AGENCIES AT BORDER CROSSINGS

Student: Dalibor PETROVSKI[1]
Mentor: Branislav BOŠKOVIĆ[2]

Abstract *– The position and connection of the railways of the Republic of Serbia with other countries in the region is very important when it is necessary to determine and improve international traffic and transit in railway transport of goods. Border crossings with their organization and technology have a very important role in that. The work of state bodies at the border crossing, which is the topic of this final paper, is especially important. Border control of state authorities at border crossings can be performed permanently, seasonally or temporarily and is a key factor on which the retention of goods and rolling stock at border railway stations depends. Considering that the transit traffic on the railways in the Republic of Serbia has a very large share, the harmonized and synchronized work of the railway and state bodies at the border crossings is of great interest. In order to raise the level of quality and competitiveness of Serbia in transit railway transport, it is necessary to work on shortening the retention time of trains at border stations, which is generally not connected with significant investments in infrastructure facilities, but significant effort is needed to coordinate work of all participants.*

The paper is dedicated to finding performance indicators of all participants at border crossings and their values in order to good management in railway border stations. Good management is aimed primarily at shortening the retention time of trains, cars and goods in them. The so-called integrated border crossing management will also be observed.

Keywords – performance indicators, border stations, SITCIN

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INDEX OF AUTHORS

Министарство просвете,
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KRUCH
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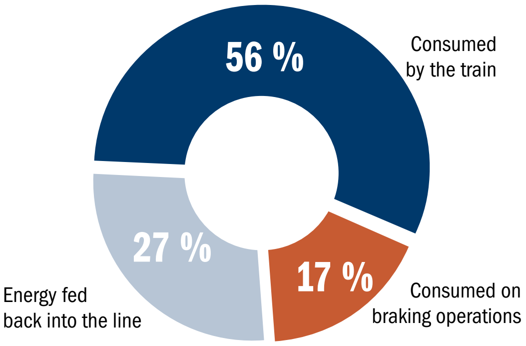
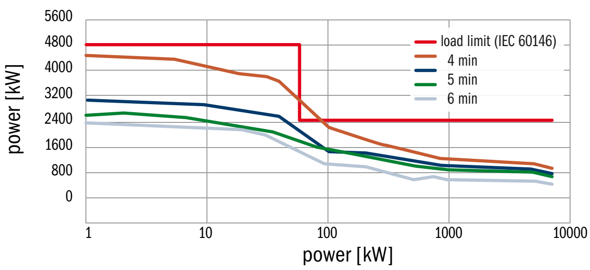
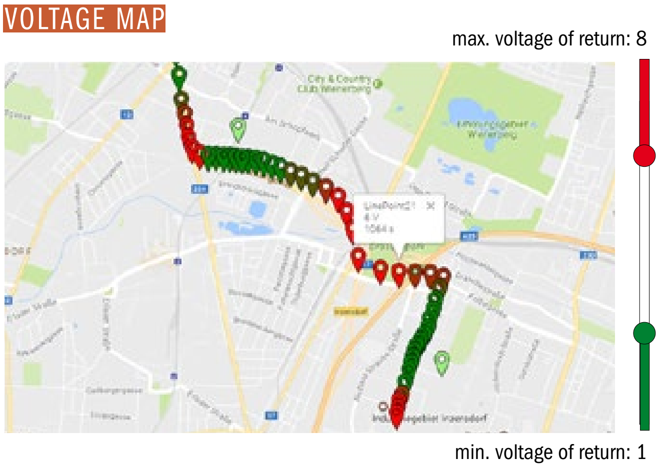
ENERGY BALANCE FOR A TYPICAL TRAIN



LOAD DIAGRAMS VS. DIFFERENT TRAIN FREQUENCIES

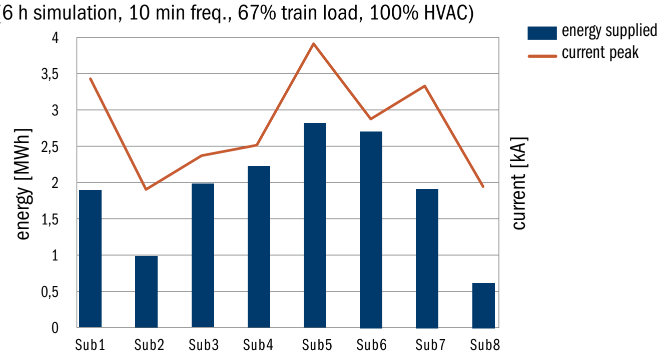


VOLTAGE MAP



ENERGY SUPPLIED AND CURRENT PEAKS PER SUBSTATION

(6 h simulation, 10 min freq., 67% train load, 100% HVAC)



Total amount of energy supplied by each substation during 6 h

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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.

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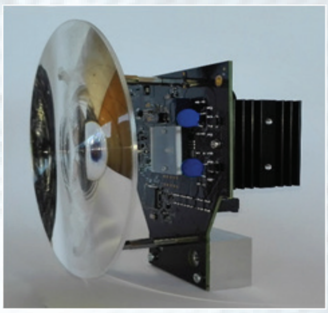
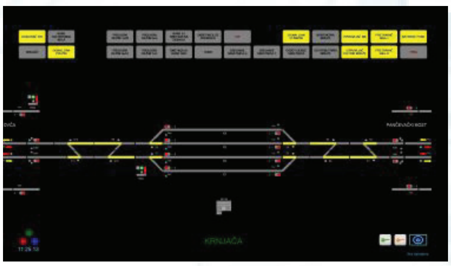


Železnički LED Signal LL-000 je izvor svetlosti koji omogućava kompatibilnost sa interfejsom klasičnih signala i rad u dnevnom, noćnom i trepćućem režimu. Takođe omogućava stalnu kontrolu pomoćnog vlakna na crvenom pojmu.

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 .

SIGNALLING & CONTROL

Company for engineering " Signalling & Control" Ltd.
Branka Krsmanovica 20, 11000 Belgrade, Serbia

SIGNALLING & CONTROL Ltd. has certificate for **Quality Management System ISO 9001:2015** for the following scope of operation: **Design and development, assembly, installation, testing, maintenance, technical checking of design, technical examination and acceptance of signalling-safety, electronic and telecommunications systems with diagnostic software on railways.**

Quality Management System
Certificate of Approval

This is to certify that the Quality Management System of:

SIGNALLING & CONTROL DOO

Branka Krsmanovića 20, 11000 Belgrade
Serbia

has been assessed and found to meet the requirements of:

ISO 9001:2015

The certificate is valid for the following scope of operation:

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Date of Certificate Issue: 3rd February 2018
Certificate Valid until: 2nd February 2021
Certified with DAS since: 3rd February 2012
Certificate Number: DAS18710862/1/Q

Authorized:

This presentation certificate is the property of SN Registrars (Holdings) Ltd and remains valid subject to satisfactory Surveillance audits Re-certification audit due before 14th January 2021

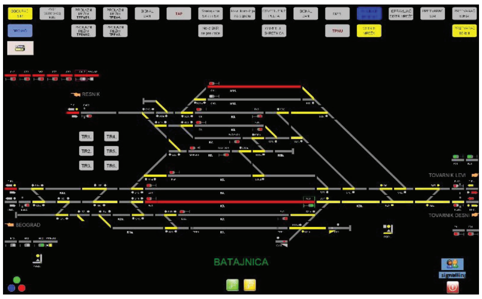
SN Registrars (Holdings) Limited, Company Number: 07659067
Registration House, 22b Church Street, Rushden, Northamptonshire, NN10 9YT, UK

SIGNALLING & CONTROL Ltd. has the following **Licenses of the Ministry of civil, traffic and infrastructure, of RS**:

- **P141E4** - Projects of control, automation, measurements and regulation for public railway infrastructures with connections;
- **I141E3** - Realization of telecommunication networks and systems for public railway infrastructures with connections.

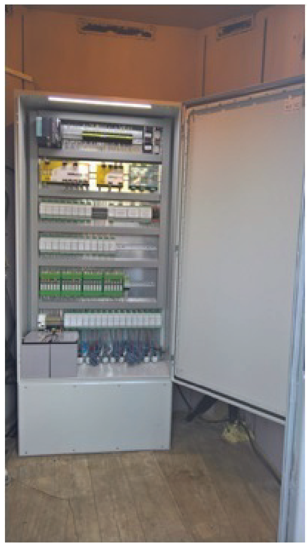
MAIN PRODUCTS:

EMMI - ELECTRONIC MAN MACHINE INTERFACE

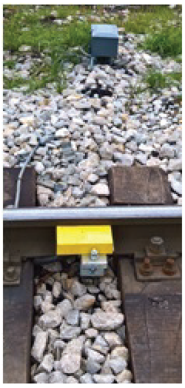


EI - ELECTRONIC INTERLOCKING (SIL4)

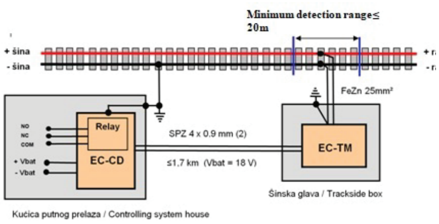
ELC - ELECTRONIC LEVEL CROSSING (SIL4)



EAC - ELECTRONIC AXLE COUNTER (SIL4) with rails continuity detection

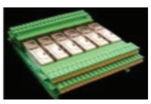


ERC - ELECTRONIC RAIL CONTACT



Detector | Trackside Module | Trackside Box.

VARIOUS MODULES FOR SIGNALLING SYSTEMS



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742 031
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UIC & IRRB RESEARCH AND INNOVATION AWARD

ELPA leading in the world in reduction of FRICTION NOISE from 96% to 99,9% at source

ELPA

- rail brakes on marshalling yards
- rails in curves
- wheel's flanges and flanks

WONROS tm technology

30 years of focused research and development of **WONROS™** technology (Wear Out and Noise Reduction On Source) **ELPA** provides to the market:

most reliable + efficient + cost-effective + environmentally friendly solutions

Version I (2020)

BREMEX ANNSYS — Prevents the generation of **friction noise** generated as side-product during the braking of wagons at the marshalling yards.

CL-E1 — Noise power reduction in curves **up to 99%** (decrease of RFN - rail friction noise **up to 30 dBA**) and reduction of wear of rails for **more than 3.3 times**.

Uses a special **environmentally-friendly material**, friction agent DBM-50.

Braking (FN) friction noise is **significantly reduced** (up to the 99,9% of sound power).

Adhesion and traction are stable and maintained - ensured balanced dynamic friction coefficient.

Noise power reduction in curves **up to 99%** (decrease of FN - friction noise **up to 30 dBA**).

All types of rail brakes

All types of rails

ELPA

All types of wheels

All types of vehicles

Same **CHFC material** can be used for gauge and top of rail.

Verified by **TÜV SÜD** Rail, patented.

No effect on the **electric conductivity**.

No compressed air needed - independant use on **all rail vehicles**.

Ensured **balanced dynamic friction coefficient** (steel/steel) - between 0.1 and 0.3.

i-ROCK — On-board **sollution** with spray applicators for reduction of **friction noise and wear** of wheel surfaces.

DRYpro ANNSYS — On-board **sollution** with touch applicators for reduction of **friction noise and wear** of wheel surfaces.

Slovenski Forum Inovacij | UIC Innovation Awards | European Business Awards for the Environment | SIQ | Bureau Veritas Certification | TÜV | unife

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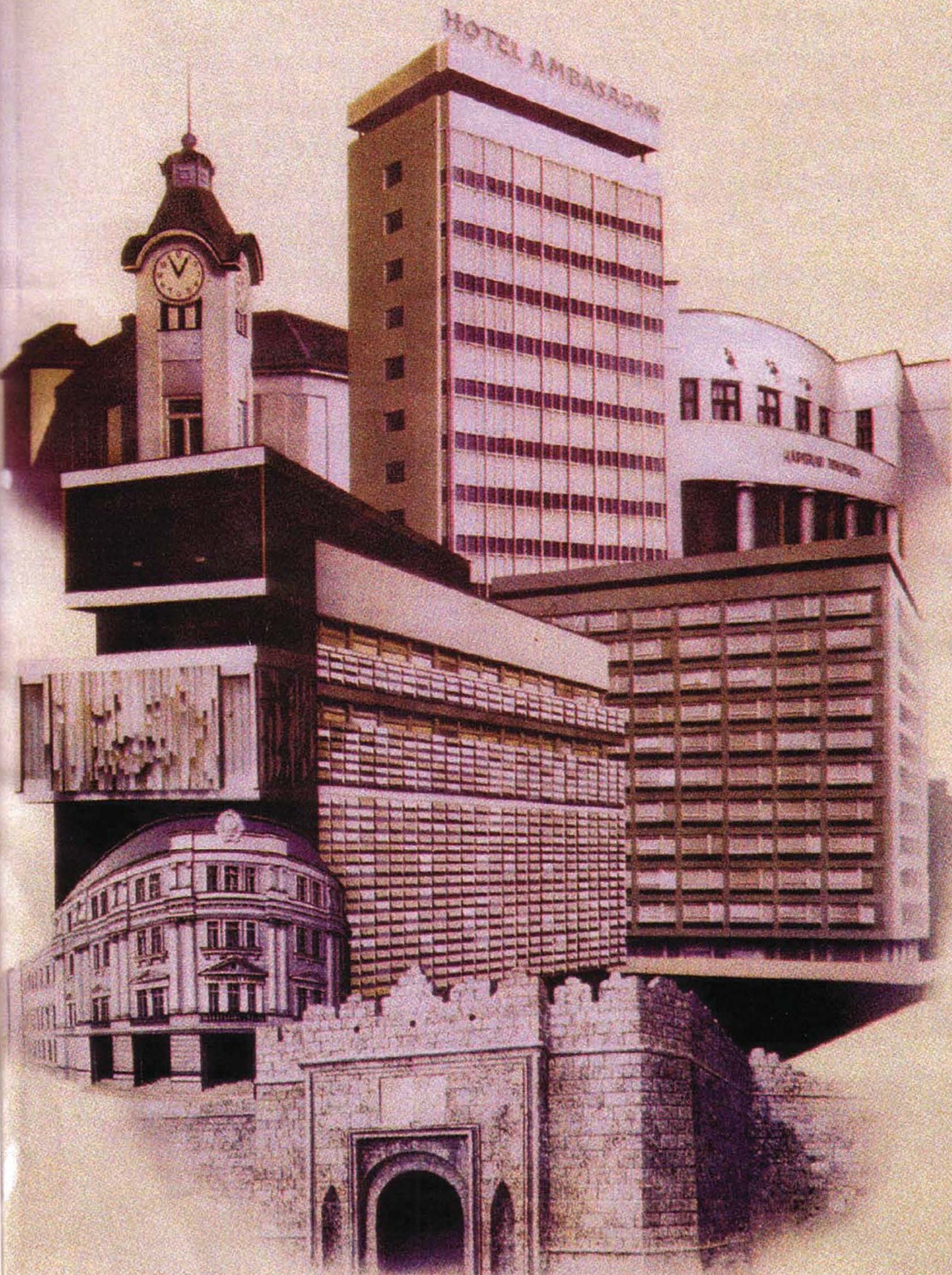
HOTEL AMBASADOR